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CRUSHING & GRINDING MACHINERY

By HARTLAND SEYMOUR
Consulting Chemical Engineer

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PREFACE

THIS book is intended to deal only with those machines which are in common use for reducing materials to a fineness of about 10 mesh. Many of the units described are capable of very much finer degrees of reduction than this, but such a field, *i.e.*, extreme fineness, is outside the scope of this work, and for information on this subject readers are referred to another volume in this series dealing with pulverizing. As far as possible I have classified the machinery described according to their principles of operation and according to the type of work for which they are suited, beginning with crushers for the primary breaking of the largest lumps and finishing with those grinding mills which will reduce to almost any degree of fineness. It will be noticed in each chapter that I have described one individual machine in much more detail than others that operate on the same principle. This does not necessarily mean that I consider the particular make described at length superior to all others. What I have done is to select what I consider to be a representative machine, one which in my judgment is in the front rank of its class, to describe this in detail, and then to deal with the other machines where they differ from the one selected or where they embody features of special interest. It would be impossible to acknowledge individually the co-operation of those firms whose machines I have described. Suffice it to say that this co-operation has been unstinted, and my sincere thanks are due to those many manufacturers who have supplied details and drawings of their machinery.

H. S.

October, 1924.

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CRUSHING AND GRINDING MACHINERY

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CHAPTER I

INTRODUCTION

THE disintegration of materials resolves itself more or less into two divisions. The first is the crushing of a metal-bearing ore to such a degree of fineness that the contained metal is released; and the second is the reduction of a substance to varying finenesses for mixture with other substances or to expose a greater surface to reaction. The first division is involved mainly in metallurgy, while the second is the problem usually met with in the chemical industries.

Though the great majority of disintegration problems fall into one or other of the above classes, no such distinction can be drawn between the equipment used. Broadly speaking, the same crushing and grinding machines and methods are applicable to both fields, and, though many laws and formulæ have been carefully worked out and endorsed by laboratory-scale and occasionally large-scale operations, such laws are subject to so many modifications when they are adapted to general crushing and grinding practice that they become practically worthless. Not even general rules for solving problems arising from the reduction of materials can be set down on paper, since these problems vary with every industry, and even the reduction of the same substance will involve different problems in different plants and localities. No useful law can be laid down—experience is the only reliable guide.

The methods of reduction may roughly be divided into three classes. First, there is reduction by batch, in which a definite charge is loaded into the machine and treated for a specified period, after which action is stopped and the product is discharged. This method is sometimes essential for very fine grinding in certain industries, but wherever possible it should be avoided, as greatest efficiency lies in continuity of process.

The second method is reduction in a closed circuit, in which the product from the machine is discharged continuously to a separator when crushing dry, and a classifier when grinding wet, where that portion which has attained the requisite fineness is released from the circuit, and the oversize is returned to the machine for further treatment. This method tends to give a more uniform product than that produced by batch grinding.

In the third system the material is fed to one end of the crusher or grinder and the discharge at the other end is continuous, there being no return for retreatment. This method is usual in coarser crushing and where a certain amount of oversize is of no consequence.

A most important factor in the reduction of any material is the instant removal of that part of the product which has been reduced to the required size, leaving the machine unhampered to deal with the oversize lumps. If this removal is not carried out a cushion is formed against which the grinding media have to work on the large particles. It requires little imagination to see that the work of the machine is thereby increased and is likely to become uneconomical.

With few exceptions reduction by stages is the best system, *i. e.*, where the most suitable crushing and grinding units are employed to effect each step of the reduction process separately, passing their product on to the next machine in the system. For instance, such a method of stage reduction might consist of a jaw or gyratory breaker for the initial breaking, say to 3 in., a crushing roll or rotary crusher for secondary reduction to $\frac{3}{4}$ in., and then a fine grinder, such as a ball or rod mill, for the final operation. The installation mentioned is for illustration only and must not be taken as a model.

It is not easy to draw a line between the various stages of crushing and grinding, since each machine encroaches more or less on the field of its neighbour. It is therefore impossible to recommend any one type of machine for any particular problem : each reduction problem must be examined entirely on its own merits, together with the conditions to be imposed, the dominating considerations being output required, ratio of reduction, nature of material, first cost and maintenance cost.

The whole secret of the efficient reduction of any material lies in a suitable crushing unit of the right capacity. This, I suppose, is obvious, but when one looks at some of the reduction plants in operation one is inclined to the belief that the obviousness of such a statement has escaped at least a few. The best way to reduce any material is also the cheapest: the energy must be proportioned to the work in hand, otherwise either the work is not being done properly or energy is being wasted.

The terms "breaking," "crushing," "grinding," and "pulverizing" are not easily defined. "Breaking" and "crushing" are often used synonymously, *e. g.*, jaw breakers and jaw crushers, gyratory breakers and gyratory crushers, though the term "breaking" should be confined only to the first fracturing of large pieces of raw material to such a size that the pieces can be crushed or ground in one of the secondary crushing machines. I have interpreted "crushing" as the reduction of a material either by impact or compression to a size not exceeding ¼ in., while by "grinding" I mean reduction from ¼ in. or larger down to 8 or 10 mesh by either compression, impact or attrition, or a combination of the three. By "pulverizing" I understand reduction to extreme finenesses—a phase outside the scope of this book.

It is obvious that no sharp or even well-defined lines of demarcation can be drawn between breaking, crushing, grinding and pulverizing; the terms overlap and many machines combine more than one of these actions. For instance, some machines will accept a feed of 3 in. cube and reduce it to a fine powder. Such machines are commonly referred to as grinding mills, though they exercise the function of crushers as well. As a general rule the term "grinding" is used when the reduction is wet.

For the purposes of convenience only I have attempted to divide the problem of reduction into three classes, viz. primary breaking or crushing, from the largest raw piece down to about 3 in.; secondary crushing or grinding, say from 3 in. down to ½ in. or ¼ in.; and final grinding, from 1 in., ½ in., and ¼ in. to about 10 mesh. Such a classification is purely arbitrary, and it has been impossible to adhere rigidly to it in the descriptions of the various types of machinery.

For primary or first reduction the jaw and gyratory breakers are most used. The product of these machines varies with their size and the material dealt with, but their field may be said to extend from a raw material in lumps weighing as much as a ton or more down to pieces which will pass a 2½ in. ring. The gyratory has a larger feed capacity than the jaw breaker, its action is continuous against intermittent in the case of the jaw breaker, and it will also work well with a choke feed, which means that the gyratory breaker is more suitable than the jaw type if a heavy output of a uniform product is desired. On the other hand, the jaw breaker will accept larger individual pieces than the gyratory, and it will also permit of a larger ratio of reduction.

For secondary reduction, say from 3 in. to a minimum of $\frac{1}{8}$ in. there is available a wider selection of machinery than there is for the primary operation. Briefly, this class includes crushing rolls (which, however, should never be used for a greater reduction than 4 : 1), some types of short-spindle gyratories, rotary crushers and various types of disintegrators and swing hammer mills. In general, the ratio of reduction with rotaries is higher than that possible with rolls, and a larger feed is also possible, so that in some cases one set of rotary crushers will do the work which requires two sets of rolls.

The crushing roll is, however, the most popular machine in many industries for secondary reduction, taking the product from a jaw or gyratory breaker, up to about 3 in., and reducing it to $\frac{3}{4}$ in.—a ratio of reduction of 4 : 1, which is economical in general practice. Very rarely should a crushing roll be used to grind finer than 8 mesh. As a general rule a good roll is an efficient and economical crushing unit, and, when operated at full load, will give results very difficult to surpass by any other type of machine in the same field.

There are a few fundamental principles which should be observed in secondary reduction. First, it is nearly always more economical to crush than to grind, that is, as large a reduction as possible should be accomplished in the primary breaking, so that a fine rather than a coarse feed is supplied to the grinding operation. Second, the product should be removed as soon as it has attained the required fineness so that unnecessary work is eliminated.

In many cases it will be found economical practice to effect secondary reduction in two stages, and, if this is done, a screen should be inserted between the two stages to remove that material which is fine enough to pass the second stage, which may then be sent direct to the final grinding mills.

For final reduction the various types of grinding mills are most used. The development of ball and rod mills during recent years has been nothing short of phenomenal, and they are now superseding many of the machines previously used for this stage. The modern ball mill is equally suitable for dry or wet grinding, taking a feed not larger than 3 in., preferably 1½ in., and reducing it to extreme fineness. The rod mill, a more recent development than the ball mill, has proved very satisfactory when operating on feeds not larger than 1 in.

In addition, there is a large number of machines for producing a granular product which cannot be said to fall specifically into one or other of the above classes, but which have been designed to meet the special problems encountered in one or more industries.

In this connection it must be remembered that it is exceedingly difficult, almost impossible, to make any useful comparisons between the various machines and classes of machinery described in this book. Even when two such machines are designed for dealing with one, or one class, of material, no such comparisons can be made on paper. The only fair test is to have the two units operating side by side on exactly the same material under identical conditions.

In considering the installation of a single crusher or a complete reduction plant the best thing to do is to seek the advice of a reliable manufacturer. The majority of the leading makers of crushing and grinding plant maintain very full records of the performances of their machinery and the conditions under which it is operating, so that they are in the best position to advise on a proposed installation when they are given full details of the problem.

When getting into touch with manufacturers for advice or a quotation on a reduction problem, there are several points on which full information should be given so as to enable them to prepare and submit an intelligent estimate. These points are, in brief :

1. The character of the material to be reduced. Special attention should be given to hardness, toughness, ease or lack of ease with which it breaks, and whether it is very abrasive, also whether it tends to break into flat pieces.

2. Quantity to be broken per hour.

3. Initial sizes of pieces to be fed to the machine. If the inquiry is for a secondary reduction machine, give the type of primary breaker or crusher, together with the maximum and minimum rejection openings of the primary which the secondary is intended to follow.

4. Size of the finished product delivered. In how many sizes will the material be screened? Is it necessary that the whole of the finished material pass the specified mesh, or may a certain percentage of residue be allowed? If so, what percentage?

5. Is the material to be ground wet or dry? What percentage of moisture is there in the feed?

6. Is the production of excessive fine material an objection?

7. Is reduction to be operated in a closed circuit?

8. Is it permissible for the material to come into contact with iron or steel or any other metal in the process of reduction? If reduction machines are now in use, what effect has the material on the wearing parts, especially any chemical action?

9. What reduction machines, if any, are now in use? What results are at present being obtained with them, including screen analyses of feed and product, capacity per hour and the power required for operation?

10. If possible send a sketch showing the space available for the crusher and the nearest driving pulley if the drive is to be from lineshafting.

11. If possible give an outline of the process to follow reduction.

If a complete reduction plant is required, the following information should also be given:

1. Character of site, *i. e.* flat or hillside.

2. How many and what classifications are desired?

3. What storage capacity is required?

4. How is the raw material to be brought to the reduction plant?

5. Is power available, or do you wish for its provision?

6. If power plant is required, give particulars, whether prime movers are to be steam, gas, oil or water.

7. Is the machinery to be operated by electric motors? If so, give characteristics, *i. e.* continuous or alternating current, voltage, periodicity, etc.

8. What labour is available?

9. Send survey or dimensioned sketch showing space available, indicating where raw material

can be delivered, and the point of dispatch for the finished product.

10. Mention any special features or abnormal conditions which may require consideration, such as climatic difficulties, boggy nature of ground for foundations, supply of water, fuel, etc.

11. Is it desired to operate any of the plant in closed circuit?

It is very important that the information outlined be as full and as explicit as possible, especially with regard to the fineness of the product desired. If, for example, 90 per cent. of the material through a certain mesh screen is satisfactory, this should be stated, since a smaller machine would be required to give such a product than one to put all the material through the screen. The reason for this is that it is much more difficult to reduce the last 9 or 10 per cent. to a certain fineness than it is to do the greater part of the previous reduction. In many cases it will be found that the manufacturers will prefer to visit the site of the proposed crushing plant to go over the details of the installation before making a proposal.

Given a type of machine suitable for the purpose in view, there are three important qualities which must be looked for. In the first place, the machine must be as fool-proof and as simple as possible and the parts should be easily accessible. Secondly, the consumption of power should be the minimum consistent with efficiency. Thirdly, the performance of the machine should not be materially affected by minor deviations from its accustomed treatment; that is to say, it should not behave badly under slight changes of diet or other operating conditions.

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CHAPTER II

JAW BREAKERS

THE great majority of jaw breakers are constructed on the Blake principle, which is illustrated in Fig. 1 (Hadfield). Here the movement of the swinging jaw F is controlled by the cast steel pitman H and the toggle plates O. This swinging jaw is held in position by one toggle plate connected to the pitman, which is in turn held by the second toggle plate, having its seat in the main frame E through the toggle cushion G and the block Q.

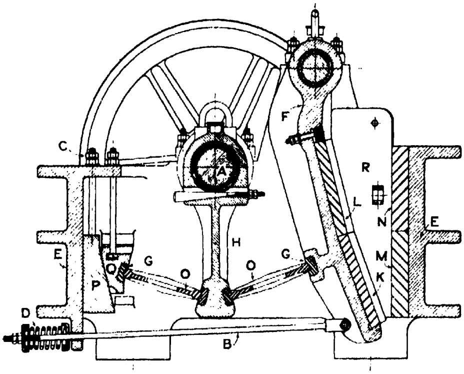


FIG. 1.—BLAKE-TYPE BREAKER (HADFIELD).

A.	Eccentric shaft.	K.	Lower swing jaw face.
B.	Drawback rod.	L.	Upper swing jaw face.
C.	Adjusting bolts.	M.	Lower fixed jaw face.
D.	Drawback springs.	N.	Upper fixed jaw face.
E.	Main frame.	O.	Toggles.
F.	Swing stock.	P.	Adjusting wedge.
G.	Toggle cushions.	Q.	Adjusting toggle block.
H.	Pitman.	R.	Cheek plates.

The pitman is carried upwards by the eccentric shaft A, the inner ends of both toggles being simultaneously brought towards the horizontal. One toggle has an immovable seat in the block Q so that the entire spreading action of both toggles is conveyed to the swinging jaw. On the descent of the pitman the discharge end of the swinging jaw is withdrawn by the rod B operated by the springs D. The size of the discharge opening is controlled by raising or lowering the adjusting bolts C actuating the wedge P.

For adjusting the distance between the swing and the stationary jaws, thereby regulating the size of the product, removable steel shims are fitted to some Blake breakers, so that by inserting additional shims the jaws are closed up, thus producing a finer grade of product. For coarse breaking one or more of these shims are removed. In one type of Blake breaker the shims are of various thicknesses, so that any desired adjustment to an extent of from 2 in. to 3 in. can be obtained without changing the toggles. The tail piece can be adjusted vertically by means of removable shims resting between this piece and the frame lugs. By removing one or more shims and elevating the tail piece through the adjusting bolts, the angle of the rear toggle is increased, and this, of course, increases the stroke of the swing jaw. Conversely, by lowering the tail block and inserting more shims the angle of the toggle is diminished and the stroke of the jaw is less. A variation of about 50 per cent. can be made by this adjustment so that the jaw movement can be regulated to suit the material being worked upon, and the capacity of the breaker can also be adjusted. As a general rule for coarse work and large capacity a long stroke is desirable, while for finer breaking the short stroke is advisable.

In another type of breaker, which is substantially of Blake design, the fixed jaw, instead of being vertical, is inclined to approximately the same angle as the swing jaw. The purpose of this modification is to ensure that half the weight of the material being broken shall be borne by the frame, resulting in a greater breaking moment with less power. In addition, this means that larger pieces of material can be accommodated in the mouth of the breaker than if the fixed jaw were vertical.

It follows naturally that such a breaker must be equipped with a deep crushing throat to obviate the possibility of material being squeezed out at the top instead of being nipped between the jaws. Another novel point in this design is that the weight of the pitman is compensated by links and coiled springs on each side, the idea being to take the weight of the pitman off the shaft.

Several modifications of the Blake principle have been introduced which are well worth a study. One of these is the Bigelow breaker. It will readily be understood that in the Blake design as shown in Fig. 1 the work of breaking is done on the up stroke of the pitman : the Bigelow breaker reverses this principle, the swing jaw being carried towards the fixed jaw on the down stroke of the pitman. In appearance the Bigelow differs little from the conventional Blake, except that the toggles are inclined upwards from their seats in the main frame and swing jaw towards their seats in the pitman instead of downwards.

It is claimed for this design that the pitman being in compression instead of tension its liability to breakage is reduced. Further, that the breaking operation is assisted by the weight of the pitman, and also that as the pitman is lifted on the opening of the jaw the turning moments of the eccentric are equalised.

The single-toggle or roll jaw breaker is shown in Fig. 2 (Hadfield). Here the jaw stock, F, carries the swinging jaw, K, being pivoted on the eccentric shaft, A, journalled in bearings forming part of the main frame, E, the elliptical movement of the swing jaw being secured by the turning of the eccentric shaft actuated by the flywheel, Q. As in the Blake, breaking is effected between the swing jaw, K, and the fixed jaw, L, which is rigid with the frame, E, the breaking movement being modified and controlled by the single toggle plate, M. The fixed jaw is vertical while the swing jaw is usually inclined from it at an angle of from 15 to 20 degrees.

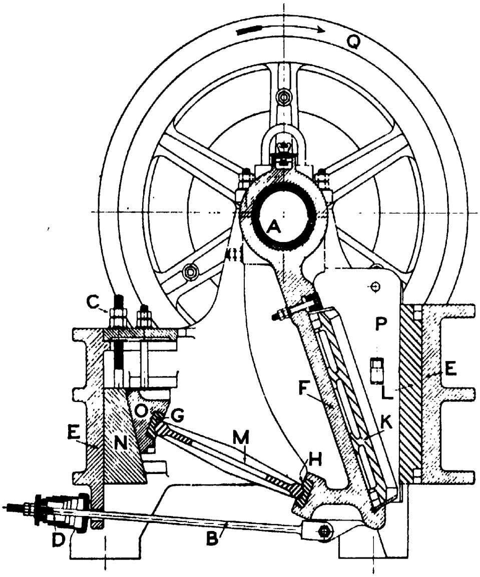


Fig. 2.—Single-toggle Breaker (Hadfield).

A. Eccentric shaft.
B. Drawback rod.
C. Bolts for adjusting wedge.
D. Volute spring.
E. Cast steel frame.
F. Swing stock.
G. Toggle cushion.
H. Toggle cushion.

K. Swing jaw.
L. Fixed jaw.
M. Toggle plate.
N. Adjusting wedge.
O. Toggle block.
P. Cheek plates.
Q. Flywheel with pulley preparation.

The adjustment between the lower ends of the two jaws is accomplished by the adjusting bolts, C, which vary the position of the toggle block, O, thus making the corresponding variation in the distance between the jaws.

These breakers are constructed in a wide variety of sizes for different capacities. For instance, the single-toggle type, with a feed end opening of 10 in. by 6 in., has an output of from 3 to 5 tons per hour, based on the breaking of hard limestone to 2½ in. ring, consuming 6 h.p. at 250 r.p.m. Such a machine is 3 ft. long, 2 ft. 11 in. wide and 3 ft. 6½ in. high, and weighs 25 cwt. This breaker is, of course, a mere toy compared with the Blake breaker with a feed opening of 84 in. by 60 in., breaking 400 to 500 tons per hour to 9 in., requiring 300 h.p. at 125 r.p.m., and weighing 20 tons. The speed of these breakers usually varies between 125 and 250 r.p.m.

Fig. 3 is the Sturtevant roll jaw breaker, in which the pitman of the Blake type has been displaced by a powerful cam and roll action, the force of this action being such that the cast-iron frames were found to be too weak, and plate steel has been substituted. The cam and roll in this breaker have long contact surfaces, not indicated in the drawing, so that wear is spread out and jar is absent.

On account of the double cam the breaking jaws have two strokes to each revolution of the shaft, which means that the machine can be operated at a lower speed, reducing vibration and minimising the danger of hot bearings. Another feature of this breaker is the heavy rear casting for holding the frame plates as rigidly at the back as at the front. This casting carries the driving shaft in bearings which are independent of the frame with the object of maintaining alignment under all conditions. The side plates are bolted together, but the bolts do not take the strains of breaking because the front anvil jaw casting is rabbeted to the side plates and absorbs the shocks.

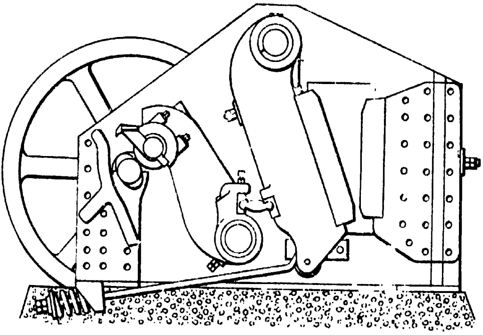


FIG. 3.—STURTEVANT ROLL JAW BREAKER.

These breakers will reduce to $1\frac{3}{4}$ in. with a capacity ranging from 5 to 7 tons per hour with a jaw opening of 8 in. by 10 in., to 34 tons per hour with a jaw opening of 12 in. by 26 in. The same design is constructed in small sizes for breaking to $\frac{1}{2}$ in. or smaller. The laboratory machine, for instance, with a jaw opening of 2 in. by 6 in., will reduce from 250 to 600 lb. per hour to $\frac{1}{8}$ in. with $\frac{1}{4}$ h.p. turning at 350 r.p.m.

The Dodge breaker (Fig. 4) is suitable for small outputs of dry materials, or for dealing with the product from a Blake or gyratory crusher. It has also been used successfully as an intermediate unit between the Blake and crushing rolls to produce a finer feed for the rolls. It is also well adapted for preparing the feed for a Huntington mill or a Hardinge conical mill. It should never be used if the material has any tendency to stick, such as talc or clay; if employed on these or similar substances it will quickly choke up.

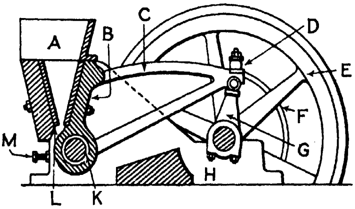


FIG. 4.—DODGE BREAKER.

A. Feed.
B. Movable jaw pedestal.
C. Bell lever.
D. Rubber buffer.
E. Flywheel.
F. Driving pulley.
G. Connecting rod.
H. Frame.
K. Shims.
L. Discharge.
M. Set screw.

This breaker differs from the Blake in that the swinging jaw is pivoted at the bottom, where the material is discharged after being broken, so that a more uniform product than is possible with the Blake is secured, the greatest movement of the Dodge jaw being at the top, while in the Blake it is at the bottom of the swing jaw.

The Dodge breaker is equipped with heavy hammered steel shafts and trunnions, safety plates being inserted behind the jaw trunnions which break if any uncrushable material is fed to the machine, thus protecting the more costly parts from serious injury.

It has not been found practicable to construct these breakers in large sizes, and the biggest machine, with a jaw opening of 11 in. by 15 in., has a capacity up to 20 tons per hour, using 15 h.p.

Just as the feed opening of the jaw breaker varies, so the discharge is regulated in accordance with the material being dealt with and the grade of product desired. In the smaller machines the width of the discharge opening may be ½ in., and in the largest it may be 6 in. or more if very large lumps are required. From a study of Figs. 1 and 2 it is obvious that the lengths of the feed and discharge openings are the same, and it is only in width that they differ. Another dimension that varies is the depth of the breaking space or throat, which is usually twice to two-and-a-half times the width of the feed area. As a general rule, the crushing throat is deep and the swing jaw less inclined to the fixed jaw for dealing with hard materials, and is shallow with a more inclined jaw for softer substances.

The majority of the smaller breakers of the Blake type are constructed with cast-iron frames, the larger machines being of cast steel. The frame is usually cast in one piece, though some are constructed of roll-steel plates to facilitate transport. In such a case the front and back blocks are dovetailed into the side plates to obviate shearing stresses on the bolts. The cast-steel frame in many of the larger sizes is equipped with strengthening ribs or bolts to afford rigidity equal to a cast-iron frame, but at the same time permitting a great reduction in weight. The cast-steel breaker weighs about half the same size in cast iron, at the same time providing a certain amount of elasticity, the result being that the breaking strain is about six times that of the cast-iron machine.

The swing jaw, pitman and toggles are made of cast iron or steel.

The design and the material used in the construction of the jaw plates, *i. e.*, those parts of the breaker actually doing the work, vary with the type of machine and the substance being treated. For soft materials chilled cast iron is often employed, but for the harder substances a more expensive and tougher jaw is necessary. For hard materials manganese steel is a favourite metal, being found to resist abrasive and crushing action better than any other. Some jaws are smooth, but the majority are corrugated. Many of the modern jaw faces are cored so as to reduce their weight; others, such as the Broadbent, are chambered out, leaving a flat surface with small recesses cast in for securing a thin layer of spelter backing. Mason's jaw is another type consisting of a manganese steel shoe fitted with a cast-iron back and run in with spelter, the only part requiring renewal being the shoe.

Most of the swing jaw faces are straight, as shown in Fig. 3, but it will be noticed from Fig. 1 that the upper part of the face is steep. The purpose of this is to secure a good nip on the pieces and to impart an initial fracture. The jaw faces are made reversible so that the section undergoing the heaviest wear can be turned, a double service from each plate thus being available. To protect the frame at the side of the crushing throat cheek plates are fitted.

The majority of these breakers are provided with some form of safety device so as to minimise the damage arising from the introduction of tramp iron into the throat. Several designs have the driving pulley bolted to a collar which in turn is keyed to the eccentric shaft, the connection thus formed being comparatively easily sheared, the more expensive parts being saved from serious hurt. In other machines the toggles are made of two overlapping plates riveted together, any unlooked-for strain shearing the rivets without disabling the machine.

The Blake breaker on the whole is exceedingly simple and may be relied upon to operate satisfactorily even under those conditions of lack of care which usually obtain in breaking plants. The machine is essentially heavy and a firm foundation must be built for it or dangerous vibration is the result. Materials of almost any hardness may be reduced provided the jaw faces are of suitable metal and design.

One attention that should always be paid to a jaw breaker is lubrication. The machines are usually well equipped with lubricating devices, and these should be made full use of. In one Blake, for instance, the end bearings of the eccentric shaft and the pitman cap are lubricated by means of force-feed grease cylinders. The lubrication of the toggle seats is provided for by using oil cups placed in easily accessible positions and connected by metal tubes to wipers supplying oil where it is wanted.

CHAPTER III

GYRATORY, DISC AND ROTARY CRUSHERS

In the gyratory crusher the material is broken by the action of a conical head gyrating inside a concave jaw or throat. In the Gates crusher, the original of this type, the heavy outer shell is somewhat like an hour-glass in shape; it is open at the top for receiving the raw material, which, when crushed, is discharged through a spout inclined from one side of its lower lobe. From just below the mouth down to the section of smallest diameter is the throat of the machine where the actual work of reduction is accomplished. The mainshaft, suspended from spider arms which span the top of the opening, passes through the throat, and has keyed to it at that point a massive cone-shaped head, free to move within the throat walls and reinforced to withstand wear.

The action of the crushing head in the gyratory is somewhat peculiar, having both a circular and a rolling movement, approaching successively every point of the interior of the throat. This action is accomplished by causing a movement of the lower end of the axis of the shaft about a small circle, such a movement being made possible by the universal character of the spider journal at the top. In consequence the axis of the shaft is always slightly inclined to the true vertical axis of the machine. Such action results in a continuous breaking of the material, which then drops through

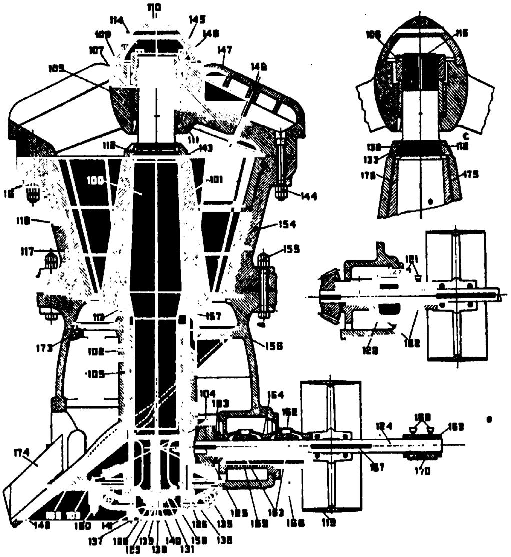


Fig. 5.—Sectional View of Superior McCully Gyratory Crusher.

100. Main shaft.
101. Chilled iron breaking head.
102. Eccentric.
103. Bevel gear.
104. Bevel pinion.
105. Eccentric bearing bushing.
*106. Adjusting nut.
107. Main shaft sleeve.
108. Spider bushing.
109. Spider.
110. Spider cap.
111. Main shaft sleeve washer.
112. Single self-tightening nut—right-hand or left-hand.
113. Dust collar.
114. Oil hole plug.
115. Adjusting nut key.
116. Upper concaves.

For 10′ and smaller.

117. Lower concaves.
†118. Middle concaves.
119. Pulley.
120. Countershaft bearing.
121. Countershaft bearing grease cup.
122. Countershaft bearing babbitt shell.
123. Countershaft wearing ring.
124. Countershaft.
125. Bevel pinion key.
126. Bevel gear key.
128. Oil pump idler pinion.
129. Oil pump driving pinion.
131. Oil pump housing.
*132. Inner self tightening nut.
*133. Outer self tightening nut.
135. Bottom plate.
136. Bottom plate wearing ring.

† For 28″ and larger.

137. Bottom plate cover studs.
138. Oil hole plug.
139. Oil pump lever pin.
140. Oil pump lever.
141. Bottom plate cover.
142. Spout.
143. Head nut lock pin.
144. Spider bolts.
145. Clamp adjusting nut collar.
146. Clamp adjusting nut.
†147. Spider.
†148. Spider arm shield bolt.
‡149. Spider rim liner—middle, right-hand and left-hand.
‡150. Spider rim liner bolt.
‡151. Chilled iron breaking head—upper section.
‡152. Chilled iron breaking head—lower section.
154. Top shell.
155. Middle joint bolts.
156. Main frame.
157. Dust collar seat.
158. Eccentric filler.
159. Lower wearing plates—shown left-hand.
160. Bottom plate studs.
162. Countershaft cap cover.
163. Countershaft oil collar.
164. Countershaft bearing cap.
165. Countershaft bearing base.
166. Oil drain pipe.
167. Pulley key.
168. Outboard bearing grease cup.
169. Outboard bearing cap.
170. Outboard bearing base.
‡171. Outboard bearing sole plate.
173. Rib wearing plate.
†174. Spout side—shown left-hand.
175. Breaking head mantle.
176. Mantle core.
‡177. Middle side wearing plate—right-hand and left-hand.
‡178. Upper side wearing plate—right-hand and left-hand.
179. Top wearing plate—right-hand and left-hand.
‡180. Lower side wearing plate—right-hand and left-hand.
181. Middle wearing plate—right-hand and left-hand.

† For 20″ and larger.

‡ For 36″ and larger.

at that point of the throat from which the head is most distant. The concave shape of the throat permits the material to be in contact only at its edges. This really results in a breaking of the material rather than crushing, the product being nearly cubical in form. The broken material falls on to an inclined diaphragm which protects the eccentric and gear, and passing over this diaphragm it discharges at the spout by gravity.

The lower end of the shaft is passed through a sleeve which is bored off-centre one-half the required gyration, the shaft being operated by a gear on the sleeve which receives its power through a band wheel. The shaft is adjustable and can be raised or lowered to regulate the size of the opening between the concaves and the conical head, thus permitting the regulation of the size of product and also allowing for taking up wear.

A typical modern gyratory crusher is shown in Fig. 5 (Superior McCully). The body consists of four main parts, the lower shell, 156, the top shell, 154, the spider, 109, and the hopper. The shaft, 100, which carries the crushing head, 101, hangs suspended from the spider, while the lower end is made to gyrate in a circular or rolling movement by the eccentric, 102. The bevel wheel, 103, is keyed to this eccentric, and motion is imparted to it by the pinion, 104, keyed to the countershaft, 124.

The movement of the shaft may be simply illustrated by holding a pencil in an upright position, the top end being held firmly, while the bottom is moved in a circle. The shaft, while being actuated in a similar manner by the eccentric, is free to rotate in either direction about its axis, thus eliminating all abrasive action in the process of reduction, which is by pressure only.

Owing to the circular or rolling movement of the crushing head, it is continually approaching successively every point of the concaves or liners, 117 and 118, while it is receding from another point, the breaking being continuous instead of intermittent as in crushers of the reciprocating jaw type.

The material to be crushed is fed into the hopper, and, owing to the wide angle of the spider rim, passes directly into the receiving opening between the crushing head and the concaves. When reduced the material falls on to a diaphragm and is discharged through the spout, 174.

In gyratory crushers of the supported type, the entire weight and downward thrust of the head and shaft is carried on a step bearing at the end of the shaft, which is the point of greatest gyration. In such a machine the burden of supporting the weight and downward thrust of the head and shaft, as well as the duty of imparting the crushing motion, is all centred at one point within the compass of the eccentric bearing.

The friction caused by the sliding action of the shaft on the supporting step imposes a heavy strain thereon, and results in heating up and the consumption of more power than is necessary. The heating is ultimately communicated through the shaft to the eccentric, sometimes resulting in melting out the babbitt lining and causing delay for repairs. In the early stages of the development of the gyratory crusher, and before finer crushing was demanded, the supported shaft type of machine fulfilled all requirements, but a demand for a more finely reduced product has resulted in the evolution of a type where the most severe work will be withstood without excessive heating or wear.

The use of the side discharge crushers in some cases is of great advantage in simplifying the arrangement of the plant. With the type of machine shown in Fig. 5 the back gear drive is omitted, and the belt for operating the screen and elevator can be run direct from the crusher countershaft, lineshaft or engine. The band wheel may be set either on the right- or the left-hand side of the crusher when looking into the discharge spout This arrangement does not compromise the machine, as there is ample room under the inclined diaphragm for the bevel pinion, and the opening in the main frame permits the removal of the countershaft bearing and pinion.

This type of suspension of the shaft and head results in an economy of power from the fact that the suspension sleeve resting on the steel supporting ring has a rolling motion without sliding or grinding. To accomplish this result the shaft must be suspended at the fulcrum point. The sliding action at the point of suspension, when it is above or below the fulcrum point, is open to the same objection as the supported shaft. An important feature is that the vertical adjustment of the shaft is accomplished without changing the set angle of the shaft.

The highly arched spider arms of the modern gyratory permit the largest lumps the machine will receive to pass underneath easily, thus utilising all the feeding space and making possible the maximum capacity of the machine. In the larger sizes of the McCully gyratory the top of the spider arms is protected by removable and reversible cast-steel shells, the object being to prevent wear.

Another feature of the modern gyratory is the arrangement of the bottom plate to drop out from below the crusher, thus doing away with the necessity of raising the entire machine to get at the working parts for inspection and repairs. To this feature has been added the oiling system, and finally the introduction of a removable bushing in the bore of the bottom plate.

The oil chamber surrounding the hub of the bottom plate is covered by a steel dust-plate, so arranged that it may be removed for cleaning when desired. A brass wearing ring is fitted between the under side of the bevel wheel and the upper side of the bottom plate hub for maintaining the proper mesh of the gears. The bevel wheel and pinion are of steel, and the former can be attached to, or detached from, the eccentric easily.

The countershaft bearing is double, each bearing being independent of the other, and both being prevented from getting out of line by machining to gauge the bearings and the shell extension carrying them. The countershaft bearing and its seating on the extension are both machined to templet, so that its position can be automatically obtained. The space underneath the bearings forms an oil reservoir, the supply of oil to the bearings being automatic.

The lubrication of the eccentric bearings, as well as the gears and the brass wearing ring which supports the eccentric, is effected by an oil pump located in the oil chamber in the bottom plate. This pump consists of two spur gears meshing together and enclosed in a tight casing attached to the bottom of the eccentric and rotating with it. The main gear is operated by a lever resting against a lug on the bottom plate. The entire pump is submerged in oil and its action is positive, there being no possibility of its operation being interrupted as long as the supply of oil is adequate. The result is a continuous flow of oil from the pump up through the inside eccentric bearing to a chamber at the top of the eccentric. From this chamber it flows down through oil grooves in the outer eccentric bearing, any surplus oil being diverted through an opening in the centre hub into the gear chamber.

Instead of a dust protector a sealing device for the eccentric is fitted, consisting of a cast-steel oil bonnet and hood, the oil bonnet being machined on the bottom and resting on the top of the eccentric, rotating with it. Surrounding this bonnet is the hood, which is shrunk on the shaft, clearance being allowed between the bonnet and the hood to eliminate wear.

The crushing heads on these machines are made either of chilled iron or manganese steel, and with either smooth or corrugated surfaces. Where the material to be crushed is soft and not of a cutting nature, chilled iron concaves and head are generally recommended, but for very hard, abrasive material manganese steel is desirable.

The chilled iron heads are made solid and bored for their entire length to fit the shaft, being secured against turning by a feather key, and held down on the shaft by two nuts. In some of the larger sizes of gyratories the heads are zinced to fit the shaft, and fitted with self-tightening nuts, forcing the head down on the taper of the shaft. Where the latter system is adopted no feather key is necessary.

It is general practice to fit the manganese steel heads with a cast-iron core or centre fitted to the shaft, the manganese steel shell or mantle being on the outside. This mantle is zinced on the inside to fit the core, and the top is ground true to form a seat for the self-tightening nut, a necessary precaution owing to the loosening of the mantle by peening and expansion of the steel. In this type of construction it is only necessary to renew the mantle when the head is worn.

The peening action on the heads of small gyratories is not particularly troublesome, consequently the heads are usually made solid as in the case of the chilled iron heads.

For the concaves or liners either chilled iron, manganese steel or a combination of both is used, depending upon the nature of the material to be crushed. In some instances the concaves are made with the upper two-thirds of chilled iron and the lower one-third of manganese steel. Each type of concave has its peculiar advantages under certain conditions of operation.

To prevent the concaves from working up when set in the machine, a rib is cast on the back near the upper end and projects into a groove formed in the top shell to receive it, thus strengthening the concaves at a vital point.

As a general rule it may be said that gyratories require less power for operation than jaw breakers, but that repair costs are heavier. An advantage of the gyratory is that less supervision is required for the feed to the machine.

A gyratory gaining in favour, especially in America, is the short-spindle machine, which is constructed in two types, the primary and the secondary. Fig. 6 shows the Telsmith primary short-spindle crusher which has a rigid central shaft which neither turns nor gyrates, resembling more than anything a huge bolt through the crusher structure. It will be seen from the drawing that this shaft and the sleeve eccentric shorten the crusher structure by about one-third, which means that less accommodation is required than for the ordinary gyratory. The crushing stroke is parallel, the eccentric acting directly on the head, producing a horizontal movement which is uniform throughout the crushing space. With a $\frac{9}{16}$-in. throw eccentric the movement of the crushing cone, both at the top and bottom of the conical head, is $\frac{9}{16}$ in. The eccentric is very long, extending from the bottom spider almost to the crown.

On its lower face the crusher cone carries a shank which fits inside and is fastened to the adjustment plate by means of a sliding key. While crushing, the head and plate operate together, but the head can be raised or lowered on the adjusting plate to alter the discharge opening.

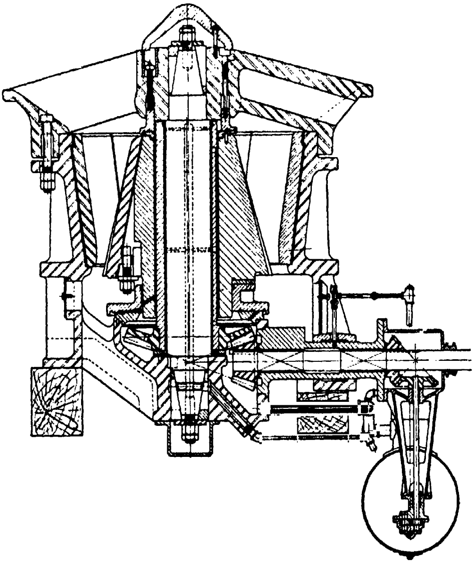


Fig. 6.—Telsmith Primary Crusher.

The primary machine discharges vertically through a three-arm bottom spider, the discharge chute being made independent of the crusher structure. The countershaft is removable, the journal being lubricated by a branch from the main oiling system, with a sight feed to regulate the flow of oil. A reserve supply of oil is kept in a tank below the crusher structure, which is easily accessible for cleaning. About one-half the oil supply is retained in the tank where it is strained and cooled before re-use.

The Telsmith primary is equipped with head and concaves of chilled iron or manganese steel, the head in the smaller sizes being either smooth or corrugated; in the larger sizes the corrugated head is standard.

The primary will crush from 12 tons to 1 in. to 325 tons to 4 in. per hour, the machine being constructed in seven sizes. The smallest crusher requires 15 h.p. and the largest 100 h.p.

The Telsmith reduction or intermediate crusher is essentially a re-crusher to reduce 4 in. to 8 in. lumps down to $\frac{5}{8}$ in. or $1\frac{1}{4}$ in. The outer structure is large in diameter, but very squat, the frame castings being made massive with walls reinforced by heavy vertical and horizontal ribs. The fundamental difference between the primary and the secondary crusher is that in the former the frame is flared outward at the top to increase the feed area, while in the latter the head and crushing chamber are flared outward at the bottom to increase the discharge diameter.

The reduction crusher is equipped with head mantle and liner plates of manganese steel, the crushing movement being a straight horizontal pinch without grinding action. The smallest machine will crush 4 in. material down to $\frac{5}{8}$ in. or 1 in. at the rate of from 10 to 20 tons per hour, using a maximum of 20 h.p.; the largest machine will crush 8 in. lumps down to $1\frac{1}{4}$ to $1\frac{1}{2}$ in. at the rate of from 50 to 90 tons per hour, using 50 h.p.

Among the gyratory breakers may usefully be examined the Symons machines, which are made in both vertical and horizontal types.

Fig. 7 illustrates the Symons vertical breaker. The capacities of these machines and the conditions under which they may usefully be operated vary so widely that it is not really practicable to put down such data as capacity, feed, product, and so forth. Such breakers find their scope in the reduction of such materials as coke, gravel, limestone, porphyry copper ores, monzonite quartz, hard pyrites and graphitic schist.

In the design and construction of the vertical breaker it has been found advisable to distinguish between coarse and fine crushing, the upper discs being modified in accordance with the product to be dealt with, all the other parts being interchangeable. For instance, under the head of coarse crushing would be classified the reduction in one pass of material 5 in. in size, such as the product from a breaker of the Blake type, down to 1 in. and finer. This means that with the discs set about $\frac{7}{8}$ in. open on the closed side, the machine will take material up to 5 in. in size.

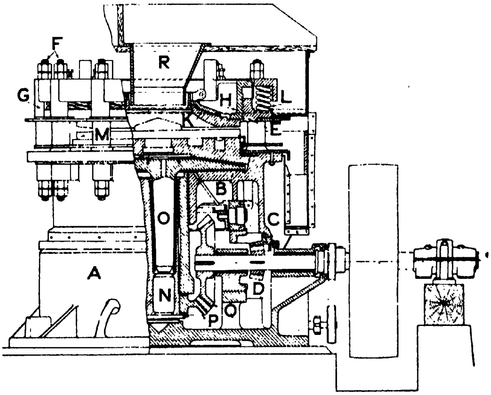


FIG. 7.—SYMONS VERTICAL DISC CRUSHER (SANDYCROFT).

A. Main frame.
B. Outer shaft.
C. Rollers.
D. Outer pinion.
E. Lower spring plate.
F. Spider bolts.
G. Upper spring plate.
H. Upper disc plate.
K. Upper disc.
L. Springs.
M. Lower disc.
N. Eccentric.
O. Ball wedge.
P. Inner gear.
Q. Inner pinion.
R. Spout.

Under such conditions the capacity is from 100 to 200 tons per hour, requiring about 65 h.p. As another example, a Symons crusher of the vertical type is reducing in one pass 3 in. to 4 in. material to $\frac{1}{2}$ in. and finer, the output being from 35 to 50 tons per hour, with 55 h.p.

Under those conditions which may be referred to generally as fine breaking, the vertical machine will take a feed ranging from 1½ in. to 2½ in. and reduce it one pass to ¼ in. and finer. Exactly what percentage can be reduced to ¼ in. depends naturally upon the character of the feed. For example, a substance which cubes readily will obviously give a larger proportion of ¼ in. and finer than one which tends to break up into small slabs. Breakers operating under these conditions have a capacity of from 20 to 35 tons per hour, depending upon the nature of the material, the power required being around 60 h.p. As a general rule setting the discs closer than 3/16 in. on the closed side is not to be recommended.

The machine consists essentially of a main frame, A, an inner vertical circular pedestal support to which is bolted a flanged sleeve around which rotates the outer shaft or driving spider, B, supported on the rollers, C, and driven by the outer pinion, D, through the outer gear. The outer shaft carries with it as it rotates the lower spring plate, E, the spring bolts, F, upper spring plate, G, and the adjustable upper spring plate, H, to which the upper disc or crushing face, K. is attached. Heavy springs, L, are placed between the upper and lower spring plates to give the necessary breaking pressure and also to act as a safety device to prevent undue strains being set up in the machine in the event of tramp iron or other uncrushable material getting between the crushing faces.

All these moving parts, with the two discs, K and M, revolve in the same direction at the rate of 50 r.p.m. The eccentric, N, which is bored and bushed to act as a bearing for the stalk of the wedge, O, is rotated inside the bushed sleeve at about 350 r.p.m. by the gear wheels, P and Q, but in the opposite direction to the two discs. The rotation of the eccentric imparts a sliding eccentric movement in a horizontal plane, or, in short, a gyratory action, to the wedge, O, as it turns. This gives through the lower disc plate a wave motion to the disc, M, and is an essential characteristic of the machine as it produces in this manner at the peak of each wave a crushing and not a grinding action.

The material to be crushed is fed through the spout into the cavity between the revolving faces and is discharged through their peripheries. The travel of the material between the feed between the discs at the centre to its ultimate discharge at the peripheries is automatic and continuous, being due to centrifugal action. The substance undergoing treatment is arrested for an instant as each of the successive crushing impacts is imparted to the lower disc at each wave crest.

Three typical capacities of this machine are as follow: 120 tons per hour reduced from 5 in. cube to 1½ in. cube with 65 h.p.; 100 tons per

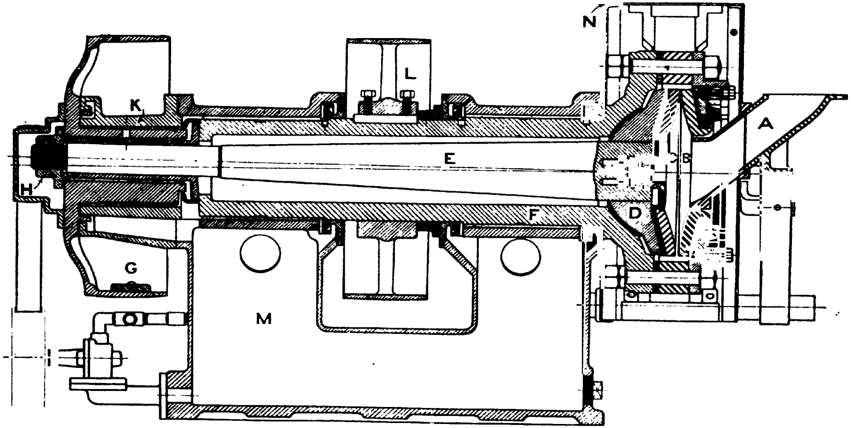


FIG. 8.—SYMONS HORIZONTAL DISC CRUSHER.

A. Spout.
B. Outer disc.
C. Inner disc.
D. Spherical bearing.
E. Inner shaft.
F. Outer shaft.
G. Eccentric pulley.
H. Nut.
K. Outer eccentric bearing.
L. Driving pulley.
M. Main frame.
N. Hood casing.

hour reduced from 4½ in. cube to 1 in. cube with 65 h.p.; 35 tons per hour from 2½ in. cube to ¼ in. with 60 h.p.; all these reductions being effected in one pass.

The horizontal form of the Symons disc crusher is shown in Fig. 8. Here the crushing is effected between two saucer-shaped discs, B and C, of manganese steel so arranged that the concave sides face each other. The outer crushing disc, B, has an opening in the centre through which the feed is conveyed by means of a hopper to the space between the discs. This disc is bolted to a strong flange which is part of a hollow shaft, F, carried in two main bearings that form an integral part of the crusher frame. This hollow shaft is rotated by a pulley, L, situated between the frame bearings.

The inner crushing disc, C, is attached to a casting which is fitted with a spherical bearing, D, at the back, which in turn is mounted on a taper shaft, E, passing through the chamber of the hollow shaft, F. The taper shaft extends beyond the end of the hollow one, and thence through the boss of an eccentric pulley, G, which rotates independently inside an extension bearing on the main frame.

The eccentric pulley does not rotate the inner shaft as it is not attached to it in any way, but merely imparts to it a gyratory motion causing the inner disc to oscillate rapidly to and fro in relation to the other disc.

The eccentric pulley is rotated in the opposite direction to that of the pulley, L, attached to the hollow shaft in order to increase the number of crushing nips in a given time. It must be understood that the two crushing discs turn in the same direction and at the same speed, the outer one revolving in a vertical plane, while the inner one, in addition, is subjected to a series of undulations causing three or four crushing strokes per revolution of the disc. As in the vertical type there is no grinding action between the faces of the disc.

These crushers are made in four sizes and will crush up to 90 tons per hour, consuming as a maximum 65 h.p. The biggest piece accepted by these crushers must not exceed 15 in. in length and 10 in. in thickness, which will be reduced to 1½ in. ring. The smallest size will reduce 4 in. material to ½ in. with 12 h.p.

Though not a gyratory machine, with which class it must not be confused, the rotary crusher may usefully be considered in this chapter, though it finds its application more in the field of secondary than in primary reduction. This machine is particularly useful for dealing with softer materials, provided they contain no considerable proportion of silica quartz, or similar cutting materials. The rotary will produce large quantities of ¼ in. or finer product without the aid of screens, with a range of output from one-quarter to 50 tons per hour.

This crusher is arranged for feeding at the top, the outlet for the crushed product being situated towards the bottom of the body. It is constructed with a central steel vertical shaft turning in babbitt bearings. On this shaft are slipped the mill stone nuts, which also carries crushing cones and an outer casing, lined with renewable hollow cones. The accelerating furrows hasten discharge and prevent clogging. A feature of this machine is that it can be regulated for coarse or fine work while in operation.

The material is reduced by a grinding action. First, the upper millstone nuts have a continuous nipping action; secondly, the lower cone reverses this action and substitutes a shredding, rubbing and millstone-grinding principle.

The discharge opening is as great as the circumference of the feed and allows the material to pass out as soon as it is fine enough. The three operations—crushing, grinding and discharge—are continuous, there being no reciprocating movement.

The feature of this crusher is that it can easily be opened out, exposing the whole of the interior for inspection, repair, or removing any uncrushable material which may have got in. These machines have a high capacity and are economical in power; for instance, one machine will crush 6 tons of gypsum to ¼ in. per hour, consuming only 15 b.h.p.

CHAPTER IV

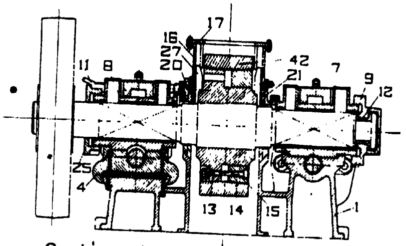
CRUSHING ROLLS

CRUSHING rolls have been very successfully used for a variety of reducing purposes in chemical and other works. For some time after their first introduction very few changes were made in the design of this type of machinery, but a more extensive use of rolls during recent years has led to considerable improvements not only in design, but also in the method of operating them. As a result of these improvements a finer product and a much greater capacity are obtainable from the modern than from the older rolls. These machines may be employed for reducing materials of various hardnesses, as well as such substances as clay and shale, and they can be operated both for wet and dry crushing. Rolls are becoming increasingly popular for certain classes of work because the operation of a good set of rolls is smooth, continuous and economical when run under proper conditions and management.

Rolls are essentially machines for comparatively fine crushing, and for this reason they are usually employed to deal with the product from either a gyratory or jaw breaker. Under normal conditions, crushing rolls may be used where the material to be dealt with is not over 6 in., when crushing in the ratio of 4 : 1, being reduced to 2 in. and downwards, the best possible results being obtained when as fine a reduction as possible is first accomplished in a breaker. As a general rule, the largest size of material fed to rolls should not, to get the best results, exceed 2½ in. It will readily be understood that the gripping capacity of a pair of rolls is limited, and any attempt to feed pieces too large for efficient nipping will probably lead to choking of the machine if the feed is heavy, and, conversely, if the feed is light, grooves will be worn in the roll shells by the riding of ungripped lumps. In any case waste or damage or both will be the result.

The double roll crusher consists essentially of a pair of identical or similar rollers revolving towards each other on horizontal parallel shafts.(see Fig. 9) These rollers are set with a fixed space between them, the material to be crushed being fed between the rolls, nipped, crushed and, on being carried into the horizontal plane of the two roller shafts, discharged.

In the majority of cases one roll is made movable so as to provide for the passage of uncrushable material without damaging the rolls. In other cases both rolls are movable, as in the balanced type. The movable roll is either held to its work by springs behind it operating against the frame, or is drawn up by springs working through tension rods. Several designers still employ the principle of fitting springs behind the roll, but in most of the later types the tension rod principle is used so as to obviate the need for the special braces. In



Section through Movable Roll. Section through Stationary Roll.

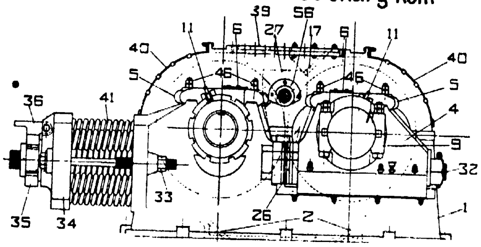


FIG. 9.—GARFIELD ROLL.

1.	Frame.
2.	End liner for frame.
4.	Sliding pedestal.
5.	Bearing cap.
6.	Oil well cover.
7.	Journal box, right-hand.
8.	Journal box, left-hand.
9.	Adjusting head.
11.	Nut lock for adjusting head or oil cap.
12.	Bronze adjusting collar.
13.	Tight roll centre.
14.	Loose roll centre.
15.	Bolts for roll centre.
16.	Housing.
17.	Feed hopper.
20.	Dust plate for moving roll.
21.	Dust ring for fixed roll.
26.	Buffer plates.
27.	Cheek plate.
32.	Tension rod.
33.	Spring guide rod.
34.	Spring guide.
35.	Tension rod nut.
36.	Nut lock for spring guide.
39.	Top cover for housing.
40.	End cover for housing.
41.	Spring.
42.	Roll shell.
46.	Bolts for bearing cap.
56.	Cheek plate for adjusting flange.

some rolls, notably the geared type, rubber springs are often employed. The movable pedestal usually slides on the frame of the machine, though sometimes it swings into position on a heavy pivoted arm, as in the swing arm roll.

It is, of course, important in adjusting the set between the rolls to maintain parallelism between the surfaces, and, to provide for this, some rolls are "synchronised," *i. e.*, the adjusting nuts are moved together automatically.

When feeding small particles, the rolls can be made of small diameter, but small diameter rolls should not necessarily be installed to follow those of large diameter for dealing with the coarse material. As the small diameter rolls are not constructed as heavily as those of large diameter, the pressure that can be exerted on the work is much less, and some of the particles may escape being crushed on account of the rolls opening up under a heavy feed. This can be overcome by employing rolls of the same diameter for the fine as for the coarse material. Another advantage of the single size is that the stock of spare parts is halved.

It has also been demonstrated that where the tonnage is large enough to warrant the first costs, large diameter rolls are more economical than those of small diameter, even when used on small sizes of feed.

Rolls vary considerably in type according to the various classes of materials for which they are designed, but for the sake of convenience they may be classified broadly under five main types—the standard or belted rolls, the geared or Cornish rolls, high speed rolls, rigid rolls and balanced rolls. The type of roll face varies considerably.

The standard roll is belt-driven at a normal speed of from 40 to 60 r.p.m., both rollers being driven. The rolls are of various diameters up to about 72 in.

The geared machine employs rolls of equal diameter, usually from 15 to 40 in. One roll may be wider than the other, the width generally being from 9 to 18 in. The wider roll rotates in fixed bearings on a rectangular frame, being direct-driven by gearing. The other roll turns in movable bearings, gear-driven from the fixed roll. The two rolls in this type of machine are usually about ½ in. apart, the space being maintained by shims or distance pieces inserted between two pedestals. Springs mentioned before prevent any further separation between the rolls unless some tramp iron or other uncrushable material is fed to the machine. The usual speed of these rolls is 15 to 25 r.p.m., the capacity being from 4 to 8 tons per hour when reducing from 1½ in. to 2 in. to ½ in. and smaller. The power required averages from 10 to 20 h.p.

The geared type of rolls has often been objected to on the ground that the set is not easily maintained after wear on account of the movable roller being gear-driven from the fixed roll. This objection is not serious when it is realised that the movable roller is, during work, actually operated by friction from the fixed roll through the material being crushed. On the whole these crushers are exceedingly reliable.

The high-speed roll is a fine crushing machine and operates at a speed of from 100 to 200 r.p.m. The faces of the rolls are narrow, being only about 6 or 8 in. wide. These machines will crush from 6 to 10 tons of $\frac{1}{4}$ in. down to $\frac{1}{25}$ in., employing from 20 to 30 h.p.

In the rigid rolls both rollers are fixed and are used only on fine material where there is little likelihood of uncrushable material being admitted. To provide against any such contingency, however, a cheap breaking-piece is inserted to save the more expensive parts. These rolls are run at high speeds and have a comparatively low capacity, though their output is regular.

Such, generally, are the divisions into which modern rolls fall. It is, however, impossible to assign every roll crusher to a definite class, so it is thought best to describe some of the better-known types and to give some indication as to the kind of work for which each is best suited.

The Garfield (shown in Fig. 9) belongs to the standard or belt-driven class, in which the rolls are so designed that oversize shells can be used to increase the wearing surface; for instance, the

42-in. Garfield roll is often equipped with shells 43½ in. in diameter. The frame of this machine consists of a box-section semi-steel casting, made in one piece in the smaller sizes, but as a two-piece structure in the larger rolls, the frames being held by fitted bolts. The pedestals for the fixed shaft bearing are cast integral with the frame, and the lower half of the housing is a part of the frame. This part of the roll housing is so designed that the crushed material does not come in contact with the housing, thus saving a good deal of wear. That end of the roll frame nearest the fixed roll shaft is cast so as to form a seat for the roll springs, and is cored out to accommodate one end of the springs. Bosses are cast on the frame for the anchor bolts—an important point where heavy tonnages of hard material are treated.

A bronze collar made in halves is placed on the end of the shaft and fits into the recess. Surrounding this collar is a cast-iron cap, also made in halves, and provided with threads to engage the threaded end of the journal box. By turning this collar either way the roll faces may be aligned to suit. When the adjustment has been made, a dog attached to the journal engages with the recess in the adjusting cap and prevents further turning of this cap. Arrangements are made to keep this bronze collar running in oil.

Springs to exert sufficient pressure for crushing materials of extreme hardness are interposed between the end of the roll frame and the spring cage. The spring cage is of cast steel, arranged to hold the springs in place and to provide a seat for the capstan nut of the tension rod.

An objection frequently made against employing high speeds for this type of roll crusher has been the difficulty of obtaining adequate nip, but with the larger rolls and choke feed the old-established standard of 1000 ft. per minute peripheral speed of the shells has been nearly doubled. Such a higher speed has been made possible by the fitting of fly-wheel type pulleys.

The output of a pair of crushing rolls adjusted to reduce to a certain size depends upon the width of the crushing faces and their peripheral speed. An increase in either or both, always given that the feed is properly nipped, results in an increased tonnage. With usual operations, one-third of the theoretical ribbon is considered good capacity, but if choke feed is employed the full ribbon may be obtained, the pressure opening the rolls slightly wider than the original set. As a general rule better results can be obtained from the use of rolls by heavy feeding and stepped reduction of about 4 : 1 in each set of rolls, but in special cases and particularly in the finer sizes larger reduction ratios are possible under constant operation.

In this type of crusher the rolls are more liberally designed than has been the usual practice, with the view of allowing easy access for inspection and repair. The two adjustments, alignment of shells and size of product, can be made while the rolls are in operation. If an extra set of shafts with the cores attached is carried in stock, these spare shafts may be equipped with new shells at any convenient time so that they are ready for immediate replacement on the rolls. The dust plates are designed to prevent the escape of dust during operation.

A serviceable crusher for obtaining a uniform product with a high capacity is the Sturtevant balanced crushing roll. In this construction neither roll is fixed, but both yield equally on encountering tramp iron or some other uncrushable material. Rolls of this type are durable and will run with very little attention, while simplicity in design is combined with rigidity of construction and easy access to the vital parts of the machine.

On these rolls the three-to-one reduction has been found the best, *i. e.*, 3 in. to 1 in. or 2¼ in. to ¾ in. If a larger reduction is required it is found more economical to employ two sets of rolls, the first reduction being from 1½ in. to ½ in., and the second reduction from ½ in. to ⅛ in.

These rolls will, when fed properly, crush the hardest material to a granular product. In the balanced construction mentioned above springs are fitted at the back of all four bearings, allowing each roll to move equally and oppositely at the same time. The springs are backed by a pair of tie-bolts on each side of the machine which register the relative position of the rolls in the supporting side frames.

These rolls will give good results when installed to obtain a product which is easily classified, and where the production of a powder is a serious objection.

The majority of these roll crushers may be fitted with either smooth or corrugated roll shells, and for many purposes the corrugated and toothed rolls are more efficient. It will easily be understood that in a roll equipped with a toothed face larger pieces can be dealt with because the nipping action of the rolls is aided by the action of the teeth, which grip and pull between the rolls pieces of raw material which would ride on smooth rolls.

In one such type of machine strong knobs or " sluggers " are cast on the renewable roll shell for breaking down the larger pieces of feed material. The opposing rows of sluggers on the shells are staggered so that those on one shell operate between those on the other. This machine belongs to the balanced type of roll crusher.

In the cubing roll, the rolls are of cast steel or manganese steel and fitted with flat-ended teeth, for cubing granite, limestone and similar substances. Such rolls are generally used in conjunction with jaw crushers and will take pieces up to 6 in. cube, reducing them to 2¼ in. cube in one pass. The teeth of the rolls are designed so that the minimum of smalls is formed. The larger sizes of these rolls with rounded teeth are often used for crushing iron ore and similar materials, in which case they are usually adjusted to crush to about 4 in. cube. A pair of rolls of this type of 36 in. diameter and 42 in. wide will crush 150 tons of iron ore per hour. The smallest of these machines, with 16 in. diameter rolls, will crush from 10 to 12 tons per hour to 2¼ in. cube, using from 15 to 18 h.p., the rolls turning at 45 r.p.m.

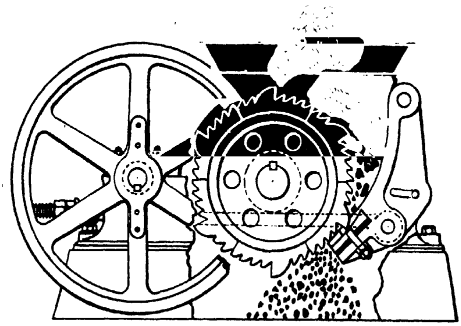


FIG. 10.—JEFFREY SINGLE ROLL CRUSHER.

The single roll crusher or breaker is a simple and economical unit finding a wide field in the reduction of coal, bone, alum, salt and similar materials; it will deliver a product particularly free from dust. The construction and operation of this crusher will readily be understood from an examination of Fig. 10, which shows a Jeffrey single roll crusher.

This machine consists of a heavy cast-iron frame mounting a toothed crushing roll and a breaker plate. The breaker plate is hinged at its upper end, and is held in position by a pair of adjustable tension rods at the lower edge. By means of these rods the opening between the breaker plate shoe and the surface of the roll can be varied to give any size product desired.

The V-shaped opening or maw formed by the stationary breaker plate and the turning roll has been so designed that, when acting in conjunction with the natural angle of repose or flow of the material being broken, the long teeth of the roll readily grip the large lumps and reduce them to such a size that they are quickly crushed to the desired size between the short teeth of the roll and the breaker plate.

As a protection against tramp iron and other foreign uncrushable material, the driving pulley of the crusher is not keyed to the shaft, but is mounted on a separate hub which it actuates through a set of wood pins inserted in holes in the pulley arm. When the crusher is subjected to any undue strain through a piece of iron or similar material being fed to it the wood pins are sheared off and the crushing roll stops, while the pulley keeps on revolving. A pair of heavy springs is fitted to the tension rods; these springs do not move under ordinary conditions, but when unusual pressure is placed on the breaker plate they yield slightly and take up the inertia of the parts, allowing time for the pins to shear without any important part of the machine being broken. A clamping effect is produced by adjustment of the cross-rod bolts between the side frames, whereby sufficient friction is brought upon the hinged breaker plate to eliminate chattering, and also to assist the safety device as described above.

Motor drive is especially suited to this machine, with a belt from the motor pulley to the band wheel. If space is valuable the pulleys and belt may be replaced by gears.

These crushers may be employed for breaking to any size from 1 in. to 6 in., and the 30 in. by 30 in. machine, for instance, will take pieces up to about 24 in. cube. The output varies, of course, with the size of the machine and the size of product; for instance the Jeffrey 18 in. by 18 in. crusher will take lumps of hard bituminous coal up to 8 in. cube and grind them to 1 in. at the rate of 25 tons per hour, consuming ½ h.p. per hour for each ton of coal crushed.

The double roll toothed crushers are particularly suited to the ordinary break-down service of certain friable materials where the product is required to be of fairly uniform sizes, but not of the average uniform sizes obtained with the single roll crushers. The rolls are fitted with renewable toothed segments or rings while a spring safety device ordinarily prevents injury to the machine from foreign substances such as tramp iron. The compression springs are held on tension rods which have a wide range of adjustment, so that a product of any desired size between 6 in. and ¾ in. can be obtained with the same machine, and the rolls can be opened wide to act as a by-pass if it is desired to let the material pass uncrushed.

These double roll crushers are all very similar in design, the principal difference between the various machines being in the toothed segments or rings which are fitted to the rolls. Several styles of these rings and segments are supplied according to the material to be reduced, and according to whether a fine, medium or coarse product is required.

The coke crushers are fitted with what are called "coke-sizers" which have the effect of reducing the coke to cube-form, the size of the product corresponding to the adjustment of the tension rod. The coke crushers are capable of dealing with up to 40 tons per hour when reducing to 2 in. and finer with 25 h.p. at 125 r.p.m.

For reducing coal to a finer product, *i. e.*, from ¼ in. or ¾ in. to dust and for making coke breeze, the rolls are run at different speeds and fitted with semi-steel corrugated segments, and a safety spring toggle is provided to protect the machine from breakage by foreign substances. A somewhat similar machine is used for crushing salt and such substances, the 10 in. by 24 in. crusher reducing 2500 lb. of salt per hour to $\frac{1}{4}$ in., requiring from 5 to 7 h.p.

Very often double or triple sets of superimposed rolls are employed for reducing run-of-mine coal to small sizes. In these machines each set of rolls is toothed or corrugated, the coal being fed to the largest toothed rolls at the top of the machine, the product then passing to smaller toothed rolls and so on, until the finished product is about $\frac{1}{2}$ in. These machines are necessarily cumbersome and cannot be made in small sizes because the opening must be large enough to receive the coal, which is generally very irregular in shape. The same machines are employed for reducing such substances as hard marl, in which case an output of 40 tons per hour with a double set of rolls is obtainable.

Unless special provision is made for securing the rolls to their foundations it is good practice to place timber sills between the roll frame and the concrete base, the roll frame being secured to the sills by bolts independent of those holding the sills to the concrete.

The springs of the rolls should always be under heavy compression when the rolls are running to secure the best crushing effect, and also to prevent any undue vibration, since it must be remembered that these are high-speed, heavy-duty machines.

When roll-steel shells are used it is advisable to heat the shell as evenly as possible before the core bolts are tightened up so that the shells will be secured more firmly by shrinkage on the core when they cool down.

Check plates should never be adjusted too close to the roll shells, especially when the feed to the rolls is large. It is found to be better practice to allow some slight spillage of the feed at the side of the roll shells, even if there is a tendency toward oversize in the roll product. A proper distribution of the feed across the roll faces, both as to quantity and as to equal percentage of sizes, is very important. The nearer it is possible to introduce the stream of raw material in an even ribbon falling vertically and directly into the opening between the roll shells, the nearer is the approach to the ideal feed. If such a feed can be arranged so as to be falling at the same rate as that at which the rims of the roll shells are travelling, the feeding conditions may well be considered as being perfect.

Daily inspection of the roll-shell faces will give ample warning of any tendency to corrugate and a proper adjustment of the feed will correct such a tendency.

Contrary to a somewhat popular impression, roll crushers give better results when operating under full load, and the reduction is also more uniform.

It should not be forgotten that where heavy rolls are installed some provision should be made for easy handling of the roll shells. If a battery of rolls is housed under one roof an overhead crane will be a paying proposition. If the crushers are used at various spots about the plant, a walking crane will be quite satisfactory.

The importance of having a uniform and continuous feed has already been mentioned. When the rolls are fed from revolving trommels and screens, or when they recrush jig tailings, the feed is usually sufficiently regular not to require a feeder. But when the rolls are fed directly from storage bins or hoppers it is essential to use a feeder to control the stream of raw material. This feeder should not be set directly on top of the roll housing because it will be in the way when the rolls are dismantled for repairs. It is also more or less inaccessible and every time the rolls are dismantled the drive connection must be disturbed. The feed is also not quite so continuous because of the short spout connections. It is, therefore, preferable to put the feeder directly on the bottom of the bin and connect it with the roll hopper by means of a light and easily removed spout. The feeder is preferably operated by a pulley mounted on one of the roll shafts so that when the roll is stopped the feed is also discontinued, thus preventing choking of the spouts.

Two diagrams of speed and capacity and horsepower tables for rolls with smooth shells and for corrugated shells are shown in Figs. 11 and 12 respectively. These are the results of a series of tests carried out over long periods and should be

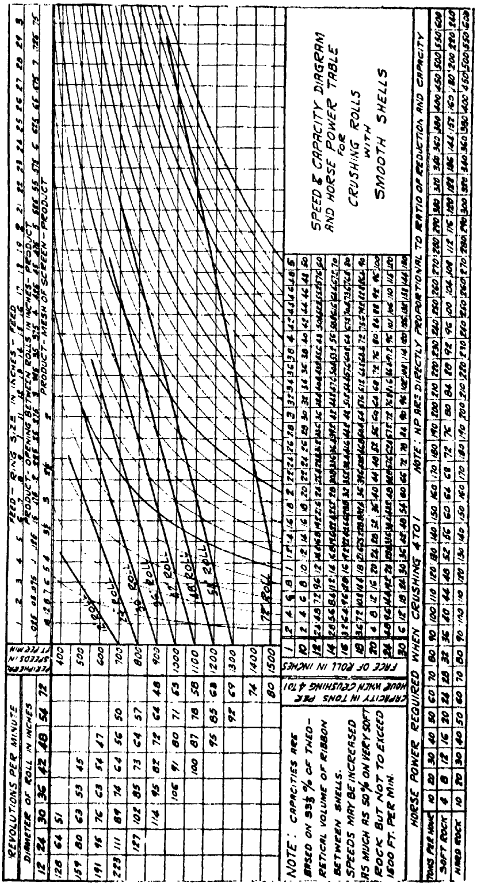
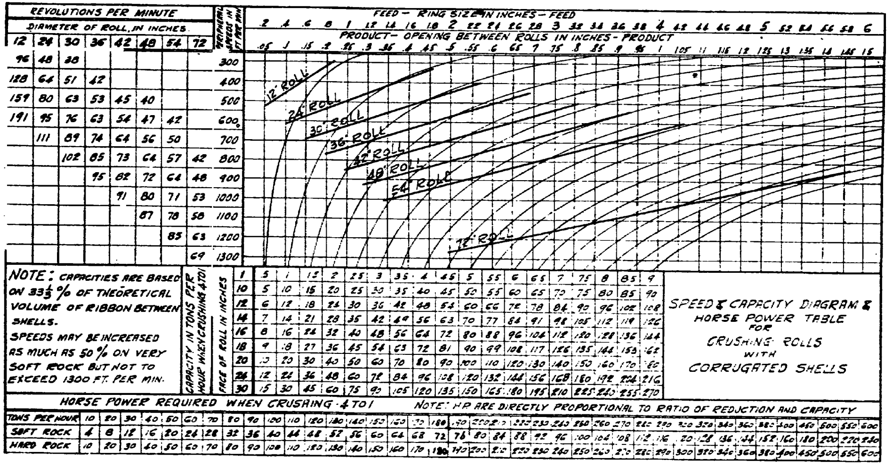


FIG. 11.—SPEED, CAPACITY AND HORSE-POWER TABLE FOR SMOOTH ROLLS.



REVOLUTIONS PER MINUTE

DIAMETER OF ROLL, IN INCHES 12	24	30	36	42	48	54	72	PERIPHERAL SPEEDS IN FT PER MIN
96	48	38						300
128	64	51	42					400
159	80	63	53	45	40			500
191	95	76	63	54	47	42		600
	111	89	74	64	56	50		700
		102	85	73	64	57	42	800
			95	82	72	64	48	900
				91	80	71	53	1000
					87	78	58	1100
						85	63	1200
							69	1300

NOTE: CAPACITIES ARE BASED ON $33\frac{1}{3}$% OF THEORETICAL VOLUME OF RIBBON BETWEEN SHELLS.

SPEEDS MAY BE INCREASED AS MUCH AS 50% ON VERY SOFT ROCK BUT NOT TO EXCEED 1300 FT. PER MIN.

CAPACITY IN TONS PER HOUR WHEN CRUSHING 4 TO 1

FACE OF ROLL IN INCHES																		
1	.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9
10	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
12	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108
14	7	14	21	28	35	42	49	56	63	70	77	84	91	98	105	112	119	126
16	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	128	136	144
18	9	18	27	36	45	54	63	72	81	90	99	108	117	126	135	144	153	162
20	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
24	12	24	36	48	60	72	84	96	108	120	132	144	156	168	180	192	204	216
30	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270

HORSE POWER REQUIRED WHEN CRUSHING 4 TO 1 NOTE: H.P. ARE DIRECTLY PROPORTIONAL TO RATIO OF REDUCTION AND CAPACITY

TONS PER HOUR	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	320	340	360	380	400	450	500	550	600
SOFT ROCK	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96	100	104	108	112	116	120	128	136	144	152	160	180	200	220	240
HARD ROCK	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	320	340	360	380	400	450	500	550	600

FIG. 12.—SPEED, CAPACITY AND HORSE-POWER TABLE FOR CORRUGATED ROLLS.

of service in deciding on the type and size of roll crushing equipment best fitted for a particular job. The diagrams show the best speeds for rolls of various diameters and sizes of feed.

The diagonal lines in the diagrams represent standard rolls of the diameters indicated and show the limit of their gripping capacities at a nipping angle of 31 degrees and a crushing ratio of 4 : 1. The gripping limits are determined with the roll shells worn to a safe minimum thickness. Rolls equipped with new shells will grip a proportionately larger size.

Below the feed size is given the ring size of the finished product in inches when crushing 4 : 1. The mesh of the cloth corresponding with the product is also given in the smooth shell diagram.

The horizontal lines in the diagrams represent the peripheral speeds given at their left ends. These peripheral speeds are controlled principally by the size of the particles fed to the machine, the roll diameters and the nature of the raw material. Rolls of large diameter can be run at higher peripheral speeds than those of small diameter, due to the smaller pressure per square inch and the lower rubbing velocity in the bearings.

When crushing a material of medium hardness the rolls should be run at the speeds indicated in the diagrams. When crushing soft or very soft substances the speeds may be increased by as much as 50 per cent., but the peripheral speeds should in no circumstances exceed 1500 ft. per minute with smooth rolls, and 1300 ft. per minute on rolls equipped with corrugated shells. No fixed laws can be laid down for roll speeds since so much depends upon the quantity and nature of the feed, and this is a matter which must be judged with extreme care, taking into consideration all the factors involved.

For the sake of convenience, the proper number of revolutions per minute for the rolls of various diameters are tabulated to the left of the corresponding peripheral speeds.

The parabolic curves indicate uniform capacity, and their values in tons per hour when crushing to the size shown are given at the bottom of the diagram for different face widths of rolls. These capacities represent $33\frac{1}{3}$ per cent. of the theoretical volume of ribbon between the roll shells, and are directly proportional to the peripheral speed and size of product.

The power required to operate crushing rolls depends entirely upon the capacity or tonnage per hour, the ratio of reduction, the nature of the raw material and the amount of loss by friction. The power required for crushing both soft and hard materials is given for different capacities.

The use of the diagrams will perhaps best be explained by two examples. Let a case be assumed where it is necessary to feed medium hard materials 1·1 in. in diameter. Directly below 1·1 (Fig. 11) is found the figure 0·275, which shows the resulting product in inches for a reduction of 4 : 1. corresponding to particles of two mesh in size. Following down the vertical line below 1·1 we find that the smallest rolls with smooth shells which will grip this material are 30 in. in diameter. From the point of intersection of the vertical with the diagonal for a 30-in. roll, following the nearest horizontal line to the left, we find that the peripheral speed should be 520 ft. per minute. In the column showing the speed for the 30-in. rolls we see that they should run at 65 r.p.m.

The nearest parabolic curve to the intersection referred to above, if followed down to the border, shows in the line of figures for 14-in. face that 14 tons can be crushed per hour.

In the horse-power table we find by interpolation that 10 h.p. will suffice to operate the rolls.

To take a second example : Let it be required to produce, under a perfectly continuous even feed, about 600 tons of 2-in. material per hour, the material being soft limestone, 6 in. ring size.

In the diagrams for rolls with corrugated shells (Fig. 12) we find a feed of 6-in. ring size indicated with a product of 1·5 in. below, which is 0·5 in. smaller than required. By reducing the feed size by this difference we obtain 5·5 in. Taking this result as the feed size, and following down midway between the vertical lines below 5·4 and 5·6 to the first diagonal line representing the 72-in. rolls, which is the size roll to be used, and running along the nearest horizontal line, the diagram shows a peripheral speed of 875 ft. per minute. Since the assumption is that soft stone is to be crushed, we may increase this speed to 1000 ft. per minute or 53 r.p.m.

The size of the product is to be 2 in. But, since the largest product shown on the diagram is only 1·5 in. let us use for convenience the 1 in. Following down the vertical below 1-in. product until it intersects the 1000 ft. per minute speed line, and then proceeding along the intersecting parabolic curve, the table indicates a tonnage of 210 per hour for a 30-in. face roll. The capacity, however, will be twice the figure, as the product is 2 in. instead of 1 in. As stated, the material will be fed perfectly continuously and evenly, hence we may take 50 per cent. of the ribbon volume, which gives us a capacity of 630 tons, or say a safe total of 600 tons per hour.

The horse-power table calls for 240 h.p. for crushing 600 tons of soft rock in one hour at a reduction ratio of 4 : 1. Since the ratio in question is 2 : 1, 180 h.p. is all that is needed to drive the rolls. Under very favourable conditions 150 h.p. would probably do.

The speeds at which crushing rolls are run are naturally determined by operating conditions and the nature of the material being dealt with. For reducing coarse materials the speed is less than for fine substances, especially if corrugated shells are fitted. When capacity is an object and the material is soft and friable the speed of the rolls may be higher than those commonly used, but, as mentioned before, this should not in any case exceed a roll surface speed of 1500 ft. per minute.

If the substance is hard and is about equal in size to the limit of the nip of the rolls, a reduction as high as 4 to 1 should not be aimed at. As an example, a pair of rolls 36 in. by 16 in. fitted with corrugated shells will take lumps 3 in. thick, and will reduce these to $\frac{3}{4}$ in. on a 4 to 1 reduction. But more economical results would be achieved by employing the rolls to turn out a 1-in. product, thus effecting a 3 to 1 reduction. In fact with most materials it may be accepted as a general rule that the larger the lumps of raw material the lower should be the ratio of reduction. On the other hand, if the lumps are well within the nipping capacity of the rolls, a higher ratio of reduction will give satisfactory results.

Just as no table or formula can constitute an exact guide to the capacity of roll crushers under any and every condition, so no strict rule can be laid down as to the horse-power required to operate them. Both these factors, capacity and power, are largely dependent upon the widely varying characteristics of the different substances dealt with. In addition other considerations arise, such as variations in the nature or size of the material itself, the question of intermittent or regular feed, the degree of fineness to which the material is to be crushed, the ratio of raw to finish product, the condition of the material, whether it be moist or dry, and the state of the roll surfaces.

TABLE OF DISTANCE BETWEEN ROLLS.

(Traylor Engineering and Manufacturing Company.)

Space in fractions and decimals of an inch, decimals of a foot, nearest millimetre and nearest screen cloth to correspond to the space between the rolls in inches, also diameter of wire in cloth.

• Inch.	Nearest Millimetre.	Decimal of Foot.	Screen Mesh. No. Mesh per Inch.	Steel Wire. Dia. of Wire, Decimal of Inch.	Screen Opening Steel Wire. Inches.	Brass or Copper Wire, Old English Gauge Wire. Inches.	Screen Opening Brass or Copper Wire. Inches.
$\frac{1}{32}$ = ·03125	1	·0026	18	·023	·0526	·023	·0326
$\frac{1}{16}$ = ·0625		·0052	10	·035	·065	·035	·065
$\frac{3}{32}$ = ·09375	2	·0078	7	·047	·096	·047	·096
$\frac{1}{8}$ = ·125	3	·0104	6	·041	·126	·041	·126
$\frac{5}{32}$ ·15625	4	·0130	5	·041	·159	·041	·159
$\frac{3}{16}$ = ·1875	5	·0156	4	·054	·196	·054	·196
$\frac{7}{32}$ = ·21875	6	·0182	3½	·063	·223		
$\frac{1}{4}$ = ·25		·0208	3	·072	·261		
$\frac{9}{32}$ = ·28125	7	·0234	2½	·105	·295		
$\frac{5}{16}$ = ·3125	8	·0260	2	·177	·323	1 mm.	= ·03937in.
$\frac{11}{32}$ = ·34375		·0286	2	·148	·352	1 inch	= ·03125in.
$\frac{3}{8}$ = ·375	9	·0312	2	·120	·380		
$\frac{13}{32}$ = ·40625	10	·0339		·207	·418	Diff.	= ·00812in.
$\frac{7}{16}$ = ·4375	11	·0365		·177	·448		
$\frac{15}{32}$ = ·46875	12	·0391		·263	·487		
$\frac{1}{2}$ = ·5	13	·0417		·225	·525		

The ideal crushing roll is strong, simple and compact, with all working parts readily accessible. The bearing should be very large and provided with sufficient lubricating devices to ensure cool running when crushing the hardest materials. Adjustments must be provided for changing the size of the product and also for maintaining the lateral alignment of the roll shells. All parts subject to wear must be made of exceedingly hard metal and so designed that they may be easily removed and renewed at comparatively small cost. The machine should be encased in a dust-proof housing provided with inspection doors. Springs of sufficient strength should be furnished to crush the hardest material and should permit of the movable roll receding when unbreakable substances accidentally fall into the machine. It should be possible to adjust the roll for the size of the product required without releasing the springs.

CHAPTER V

DISINTEGRATING MILLS

THE bar disintegrator consists of two revolving cages formed of round steel bars, reinforced with iron rings and securely fastened to heavy cast-iron discs. The bars of one set of cages project between the bars of the opposite cages, so that the disintegrator grinds by impact and not between surfaces, there being no grinding or crushing action. The materials to be reduced are introduced into the inner cage, and by the centrifugal force created by the revolving cages are projected through the cages and against each other. This process resolves itself into a system of attrition and free blows.

Bar disintegrators are used for four purposes, namely, fine reduction, coarse reduction, mixing, and a combination of reducing and mixing. They are used successfully for such friable substances as coal, iron oxide, fertilisers, and will deal with materials containing a large percentage of moisture. They may also be employed for reducing large pieces of material from 12-in. cube down to a granular product, for, if necessary, further reduction in a fine grinding mill.

For fine disintegration a four- or five-cage machine is generally used, in which two sets of cages revolve at high speed in one direction, while the intermediate cages turn in the opposite direction.

For coarse disintegration a slower-running machine with bars spaced at wider intervals is used. These machines usually have three or four cages of bars, according to the material to be dealt with and the degree of fineness desired. The output is, of course, considerably greater than that of the fine reducing disintegrators.

For certain materials a three-ring disintegrator, fitted with one stationary and two revolving cages of bars, is an inexpensive and very effective machine for reduction prior to further treatment in a fine grinding mill.

For mixing, a three- or four-ring machine similar to the coarse grinder is the general practice, while both mixing and disintegrating can be carried out in either a high or a medium speed disintegrator, the materials in question determining the more suitable of the two types.

The bed plate on one type of disintegrator is a solid cast-iron frame heavily ribbed and reinforced, with openings in the centre to allow the discharge of the material when ground. The cast-iron housings which support the cages, in which are located the journal bearings, rest on the base plate, and are planed on the bottom so that they can slide backwards and forwards, the object being that the cages can thus be separated and the mill examined without taking it entirely to pieces.

The cages run quite independently of one another, each being supported by a separate shaft and run from opposite sides. On the outer end of each shaft is a flywheel which is about the same weight as the revolving cage on the other end of the same shaft. These two weights balance one another so that the weight on the journal bearings is uniform, preventing their wearing out of truth.

The flywheels impart a steady speed to the machine which is not checked by irregular feeding of the materials into the cages, the momentum stored up in the wheels overcoming the recedence of the regular speed and thus maintaining uniform reduction.

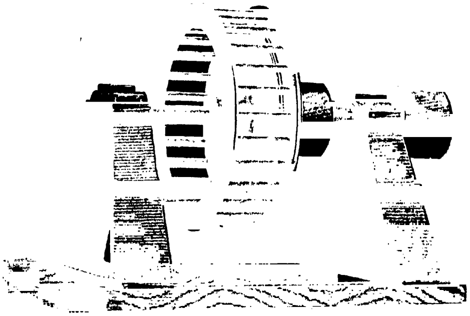


FIG. 13.—STEDMAN BAR DISINTEGRATOR.

The top of this machine is of boiler plate construction bolted on to the cast-iron box, removal for inspection of the cages and working parts being easy. The cast-iron plates which form the lower part of the hopper surrounding the cages are removable, and are replaceable when worn out.

Disintegrators of this type are constructed in various designs according to the material to be dealt with.

Some of the modern disintegrators are direct-motor driven, the cages being mounted directly on the motor shafts. The motors are attached to sliding bases, equipped with rack and pinion, and are connected to the side plates of the working chamber. In this machine, by loosening four clamps, the motors, side plates and cages can be slid out of position for cleaning. The end and top plates of the chamber are held in place by wing nuts so that the entire chamber is accessible.

These machines have proved useful in reducing pigments, linoleum colours and similar materials, where the machine must be cleaned to change from one colour to another.

For operating at high speeds, up to 2000 r.p.m., the direct-motor disintegrators are equipped with dust-tight ball bearings, and are used for such substances as lithophone, linseed oil cake, linoleum colours, printers' ink and white lead.

In the Christy and Norris disintegrator, which is of the beater type, the design is simple, the body being of cast iron with renewable linings, while self-lubricating phosphor-bronze bearings are used to secure cool running at the high speeds necessary. There is only one revolving part, and this needs no adjustment, as the fineness of the product is determined by the use of the screens or grids of different meshes, fitted into the lower half of the machine, and changeable within a few minutes.

The beaters which do the grinding are straight and interchangeable, being made of steel-faced iron or of toughened steel according to need, the latter being reversible in the newer types. They are carried in a disc of steel alloy or cast iron according to size. The handholes in the sides of the larger machines allow these beaters to be changed without opening up the whole of the machine.

The screens are of two main kinds, namely, "cast-iron screens" having steel bars in a cast-iron frame suitable for fine or coarse reduction of average severity, and "steel screens" of coarser meshes for heavier work such as on horns or bones. The cast iron framed screens are sometimes adapted for using perforated steel plate for disintegrating corn and such materials where husk or fibre has to be cut up.

In these disintegrators, the work is done by the four beaters, which revolve at a high speed inside the machine and pulverize any material fed into it. The powder thus reduced passes out through the screens at the bottom rapidly. This method is suitable for producing fine and soft meals from corn, feeding stuffs, drugs and chemicals. It is also used for such varied materials as leather, horns, bones, paper, straw and limestone, provided suitable screens are used. Some judgment is necessary in selecting the best size of machine and the most suitable mesh of screens for any particular product, and the makers' advice should be obtained in cases of uncertainty.

No definite figures can be given for the cost of operation, as this depends largely upon the nature of the material and the fineness required, and is also influenced by automatic feeding and removal. In round figures the medium-size machine taking 20 h.p. will grind about 5 cwt. of tough material such as horns or bones to a fine powder, about 30 cwt. of average friable material such as burnt limestone or soap powder, and up to 3 or 4 tons per hour of soft crystals such as sulphate of copper.

An effective unit for shredding fibrous materials such as asbestos, barks, rubber, herbs, leather and paper is one where five horizontal knives are fastened to a cylinder revolving in a circular case to which six stationary knives are secured, and set at an angle to ensure a shearing cut. The cut material passes over a perforated plate forming the bottom of the circular case; the fine particles pass through, while those too large are carried round until sufficiently reduced.

In the swing hammer mill, with its variations, the material is broken by the impact of swinging hammers on the particles as they are fed into the throat of the machine, the hammers not being rigid, but free to swing about a pin in a central shaft. In operation these hammers are swung out by centrifugal force and beat the material, not against a fixed surface as in a disc, but as they are in a state of suspension in mid-air. Fig. 14

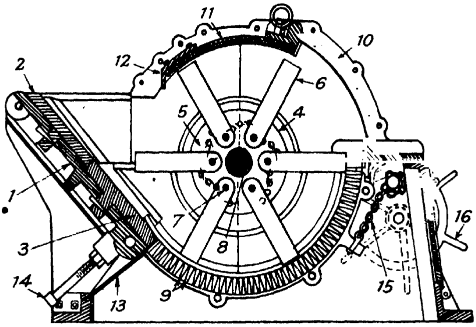


FIG. 14.—WILLIAMS SWING HAMMER MILL.

1.	Adjustable front end.
2.	Top breaker plates.
3.	Bottom breaker plates.
4.	End disc.
5.	Centre discs.
6.	Hammers.
7.	Hammer bolts.
8.	Shaft.
9.	Cage bars.
10.	Back cover plate.
11.	Front cover plate.
12.	Lip plate.
13.	Material shield.
14.	Adjusting screws.
15.	Cage lowering and raising chains.
16.	Pilot wheel.

illustrates a modern swing hammer mill of the Williams type, which consists essentially of hinged hammers, disc plates which hold the hammers, breaker plates where most of the crushing and grinding is done, and a cage for regulating the fineness of the material discharged; all these features being encased in a housing and mounted in journals.

Reduction in this mill is effected by a combination of abrasion and percussion. Keyed to the shaft is a series of discs which carry through their outer diameter bolts on which are hinged sets of hammers, each having an arc of free movement approximately one-third of a circle. As the machine is started and reaches its normal speed, the hammers, on account of the centrifugal force set up by rotation, take up a position divergent from the centre of the machine, when the machine is ready for the material.

Some idea of the effect of this continual beating administered by the hammers may be grasped when it is remembered that there are four to six sets of hammers to each machine—there may be from four to thirty hammers in each of the rows according to the size of the machine. For instance, in a machine with thirty hammers in each of the four rows, when running at 1000 r.p.m., each set of hammers strikes 30,000 blows, or a total of 120,000 blows per minute. The hinged suspension of the hammers imparts a flexibility quite different from any other type of crusher or grinder.

In these machines all the parts can be regulated so as to preserve the breaking efficiency of the crusher after wear. The hammers are adjustable to the breaker plate and cage by a series of holes in the disc plates, thus maintaining the diameter of the grinding cylinder to ensure a uniform product. The breaker plate may also be adjusted to the hammers so that the point of contact between the ends of the hammers and the plate may not vary. Where the sectional cage is used the general practice is to adjust the cage to the hammers one-quarter of an inch at a time to maintain the diameter or circumference.

Alternating discs are fitted to the machines which alternate or stagger the hammers so that the entire chamber is covered by the hammers and no gaps are left for material to escape the reducing effect. Thus, if there are 20 hammers in the first row, there would be 10 hammers in the second row, and so on, the hammers in the second row following in the path between those in the first row and in that space which is occupied by the preceding discs.

The disc plates are equipped with holes, five to nine in number, to permit the adjusting of the hammers, and thus enabling wear from 1½ in. to 4 in. at the hammer points to be taken up. When the hammers are worn ½ in. or 1 in. the set is removed, the hammers are cut off square and to equal length, and then reinserted in the machine by advancing the hammer bolt two or three holes.

The machine first passes over the breaker or grinding plate which adjoins the grinding cage, and it is here that about 75 per cent. of the reduction is done. This plate can be adjusted inwards towards the hammers while the machine is in operation by screws on the outside of the machine. These plates have a throw of from 1 in. to 2½ in., depending on the size of the machine, so that the operator is able to keep the plate in close to the hammers to ensure a uniform product.

The cage bars are replaced by inserting new bars or sections into a recess in the side of the housing. These recesses are on each of the side frames of the housing and are cored to the same circle as the outside diameter of the hammers. The cage sections are composed of about three to four bars, riveted together with spacing washers between, and the operator can, if he so desires, take out these cage bars, secure a set of spacing washers either larger or smaller than those in the machine originally, clip off the rivets, take these apart, put in new spacing blocks or washers, and thus have a larger- or smaller-opening cage with the same bars.

In replacing any of the cages in these machines, whether of sectional design, perforated metal or diminished bars, the operator raises the cover, which is hinged on the smaller machines, and pulls out the section to renew the bars. When the change has been made, the cage sections are slipped back into their grooves, the cover is lowered and secured by two bolts. The cover divides behind the hopper so that, if the chute rests on the hopper, it is not disturbed when the cover is raised or lowered.

The cage is adjusted towards the hammers by means of a hand wheel on the outside of the crusher. When the machine is in operation the cage is locked in position. If a piece of tramp iron or other uncrushable material gets into the machine, the operator releases a pawl from the ratchet wheel, turns a hand wheel, and the cage drops by its own weight. After the crusher is relieved of the iron the hand wheel is turned in the opposite direction and the cage raised slowly to its working position, where it is locked.

The object of the dumping cage is to relieve the machine when it becomes choked. Occasionally a fuse will blow out, a belt will break or jump off the pulley, or the power fails, stopping the crusher. In large operations where there is no automatic feeder on the machine the machine will fill up with material while stopped, and if it were not for the dumping arrangement the cover would have to be removed and the material dug out.

It is naturally important that the entire housing of a grinding mill of this type be protected by liner plates. This is effected either by a steel plate lining from ¼ in. in thickness up to a chilled iron lining of 1½ in. thickness, depending on the size of the machine and the purpose for which it is used. A machine grinding soft material can be lined with ¼-in., ⅜-in., or ½-in. steel plate; one dealing with hard material with a considerable amount of impurity is lined with 1½-in. to 2½-in. chilled iron. These liners are held in position by tapered keys on the outside of the mill housing.

The housing is made in eight separate sections, so that should an accident befall one section the crusher can be made as good as new at small cost. Each of these sections can be replaced without taking the machine off its foundation or throwing it out of line.

These machines are, of course, built to almost any size and are adapted for dealing with any material from the hardest rock to garbage. For instance, one mammoth swing hammer mill delivers a 33-ton blow with each hammer, there being three sets of nine hammers, or 27 in all; run at a speed of from 600 to 700 r.p.m., something like 18,000 33-ton blows are delivered per minute. The hammers are usually of manganese steel, and, when a uniform product with the minimum of fines is desired, are arranged to alternate, long and short. One of these machines is dealing now with 700 tons of stone per day at a cost of about 3*d*. per ton.

A feature of these machines which allows a wide range of utility is the hammer. This can be varied according to the material being dealt with, and there is a hammer to deal with almost every known substance. The ordinary straight hammers are the most widely used of all, and they are recommended for granular work because they administer a good square blow and minimise the fines. The twist hammer is another favourite. Where a 3-in. by 1-in. hammer is used in round discs there is a space of 1 in., or the thickness of the discs, between each hammer. In order to cover what would otherwise be wasted space the hammers are twisted $\frac{5}{8}$ in. on the end. One row of hammers is twisted towards the right and a second row towards the left, so that when the machine is running the material is sent zig-zagging across the cage, the result being a finer product and a somewhat greater capacity. Such a hammer is specially adapted for medium fine grinding.

For the disintegration of sinewy, fibrous substances a chisel-pointed hammer is used which delivers a shearing, shredding blow on such materials as alfalfa and other herbage, woods, roots, rags and the like. There are perhaps more than fifty different hammers designed, and to describe each here would be out of place.

The degree of reduction attained in these mills is determined to a very large extent by the intensity of the blow administered by the hammers, and so different degrees of fineness may be attained by varying the speed of the machine without much regard to the other parts. Different materials and different conditions of the same material as regards temperature, moisture, etc., will show a corresponding difference in the degree of reduction so that it is impossible to foretell with accuracy the results from any particular material. The best course is for the engineer or chemist to submit a sample of about 50 lb. to the several manufacturers and obtain their quotations as regards type of machine, capacity and other particulars.

Similarly, the amount of wear cannot be predicted on account of the varying natures of the materials dealt with. Silicates, whether hard or soft, have an appreciable influence on the hammers and bars of these mills, and, as a very general guide, it may be said that substances containing not more than 5 per cent. silica are permissible for reduction in these mills; from 10 to 15 per cent. is doubtful; 20 to 25 per cent. is dangerous; and over 30 per cent. is prohibitive.

The size and pieces which may be fed to the swing hammer mill depend upon the hardness of the material and the size of the machine. For the smaller machines when dealing with hard stone a feed not exceeding 3-in. cubes is ideal; and capacities are usually estimated on this basis. Softer substances of the nature of bituminous coal may be twice as large, while barks and fibrous materials may be as large as the feed will accommodate. The supply may be fed by hand or charged directly into the machine from a conveyor or elevator. When taken directly from a bin some sort of automatic feeding device is necessary.

In another type of mill the work is done by either two or four alloy steel swing hammers placed at equal distances from each other, and connected at their ends with two parallel discs which act as flywheels and turn at 360 to 1600 r.p.m.

There are, of course, numerous other machines on the market which crush on the swing hammer principle, but they differ very little from those already described.

One of the most popular methods of driving swing hammer mills is by direct motor drive through a flexible coupling. Another method is by belt drive from a motor, when any speed desired can be had by means of suitable pulleys on the motor and the mill. The motor should be on the same level as the mill and the belt drive horizontal, the lower strand of the belt being the pulling side. Where steam power is used the countershaft belt drive is nearly always found. The countershaft should be placed between the mainshaft and the mill, and should be from 18 ft. to 20 ft. from the machine, directly behind it and as near the same level as possible so as to give a horizontal drive.

It must be realised that these mills belong to the high-speed order, and as such should be set on a good substantial foundation; the small mills may be mounted upon heavy floors, but the large ones should be set on a brick or concrete foundation. In setting these large mills a timber frame of ample proportions should be anchored to the foundation and the machine bolted to this frame. The idea of the timber frame is, of course, to impart a certain amount of elasticity and to act as a cushion.

In the centre of this foundation, and the full width of the inside of the machine, there should be a large chute passing down to a conveyor for delivering material to an elevator. This chute should be at an angle of not less than 45 deg.; 60 deg. is better, thus allowing the material to pass freely from the mill and down into the elevator.

If an elevator is installed it must be of sufficient capacity to handle at least 30 per cent. to 50 per cent. more product than the output of the machine, because there is often a certain percentage of oversize that is screened out and returned to the mill for further operation. The elevator must be of sufficient height to discharge into a screen of ample proportions. This screen should be set well above the mill, say, two floors above, so that there will be plenty of gravity fall for the return of the oversize for treatment.

Where a screw or spiral worm conveyor is used for removing the finished product from the mill, it should be not less than 4 ft. or 5 ft. below the base of the machine, and the hopper angle from the width of the mill inside down to the width of the conveyor box must be very steep. The conveyor should be of ample capacity to remove all ground material, as this must never be allowed to bank up under the mill or it will prevent the free exit of the product through the grate. If the mill is of large capacity a screw conveyor is not recommended, as it is too slow in operation.

If a belt conveyor is used, as it often is where the mill capacity is large, it should be about equal in width to the inside of the grinding mill, placed and run from front to back of the machine. The product should never be taken away sideways or parallel with the shaft. In erecting the belt conveyor, place it at least 5 ft. below the base of the machine, and see that it has a capacity of 30 per cent. to 50 per cent. greater than that of the mill.

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CHAPTER VI

CENTRIFUGAL ROLL MILLS

In the centrifugal roll or pendulum mills, as they are variously called, the work is effected by one or a number of suspended rollers running around the inner surface of a ring die, the rollers themselves rotating about their own centres. In this principle the pressure between the rollers and the ring effects the grinding action, and is derived from centrifugal force. The material to be reduced is fed into the annular space, moved into a position between the rotating rollers and the ring die and is there ground.

The two main types of this system of crushing are the vertically carried systems shown in such mills as the Huntington and the Griffin.

In the Huntington Mill (see Fig. 15) the ring die is usually made of a hard steel of a diameter to suit the duty required, varying from 3 ft. to 6 ft. This die is carried in a heavy circular pan casting held in position by metal and hardwood wedges. The bottom of the pan is also fitted with a renewal false bottom usually of hard white iron. In the centre of the pan is provided a protected boss and journal for carrying the centre shaft. Upon the pan casting is bolted in section a cast-iron housing of suitable size and shape, provided with orifices in the lower periphery carrying renewable screen plates. The housing is also equipped with a launder to enable the wet ground slurry to be concentrated at one delivery point. A feed opening or chute is also fitted in the top of the housing to guide the material to be ground into the grinding chamber.

The rollers in this mill are four in number, and are carried by means of spindles in rocking sleeves so as to move freely radially. These rocking sleeves are provided with horizontal spindles and hang easily in bearings in the spindle and scraper carrier. The scraper carrier is shaped in the form of a toothless wheel with specially arranged

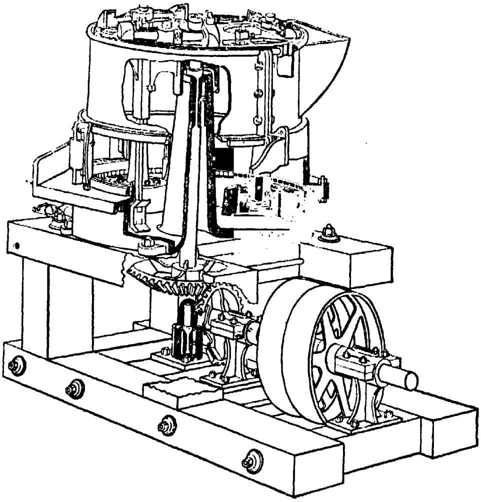

FIG. 15.—HUNTINGTON MILL.

arms to provide the necessary brackets for the rocking sleeves and also for the stirrers and scrapers, and is keyed to the centre shaft, rotating with it. To the centre shaft is bolted a bevel wheel actuated by a pinion and fast and loose pulleys, giving the necessary purchase for effective action. The shaft is carried in two bearings, *i.e.*, the footstep and the pan casting bearing, which latter is of such length and design as to prevent lateral movement and to protect it from wear due to "splash."

It will be noted that when at rest the grinding rollers lean slightly inwards so that the centrifugal action during motion is augmented by gravity in promoting the grinding efficiency. The whole mill is usually carried upon a timber structure, which by its resiliency obviates metal fatigue due to constant vibration during action.

The Huntington mill is essentially for wet grinding, although it is used by a slight alteration for dry grinding. The material is fed into the delivery chute of the upper housing, drops into the bottom of the pan casting, where it is acted upon by the scrapers which keep it in motion, throwing it against the ring die and under the crushing rollers.

The action of the rollers and scrapers sets up a wave or splash constantly beating against the screens, enabling the fine slurry to pass through and down the launder to the delivery end, the coarse material falling back for further reduction.

The application of the Huntington mill is limited to the reduction of moderately soft material not greater than about ¾ in., from which a granular product is obtained. It has found its field in crushing and amalgamating gold ore, also for crushing ores direct for fine concentration, and for crushing the tailings from jigs in coarse concentrating mills for subsequent treatment on Frue Vanners or other slime concentrating machinery. For the latter purpose the machines receive the coarse tailings from the jigs, which average about ¼ in., and crush these down to 20 mesh or finer, the capacity being about 75 tons per day. The power required by the 6-ft. mill is 12 h.p.

In operating the mill it is advisable to shut down every 12 hours to oil the vertical shaft, and to put a drop or two of oil on each of the stems of the rolls, care being taken that none of this oil gets into the mill. When these stoppages are made the mill should be examined to see that the rolls have not dropped down, and that they have not for any reason become stuck so that they cannot be turned round by hand at the bottom, and also that the scrapers have not dropped, worn off, or are not too high.

The Griffin Mill shown in Fig. 16 is similar in design to the Huntington mill except that the work is accomplished by a single roller running

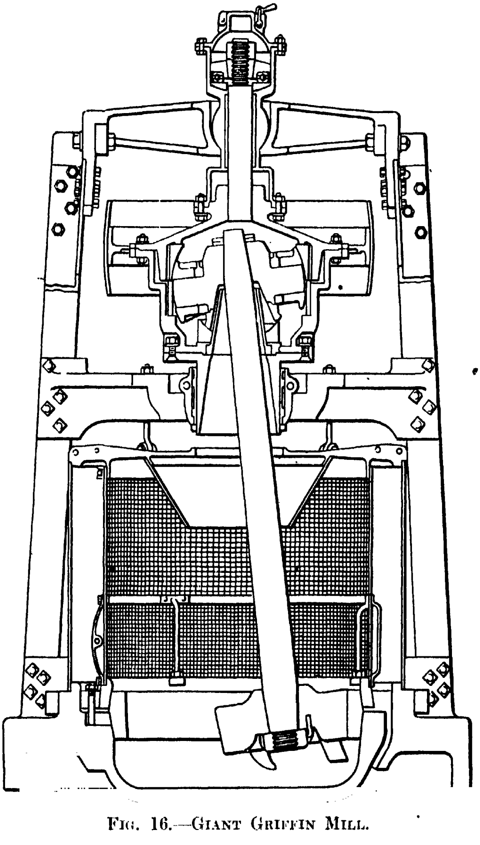

FIG. 16.—GIANT GRIFFIN MILL.

within and against the inner surface of a ring die, being held in contact with it by centrifugal force. The Huntington mill is, of course, a wet grinder, while the Griffin mill operates dry. The roll on this machine is suspended by a shaft from a universal joint fitted inside a pulley revolved horizontally. At rest the roll hangs central, but when the machine is started up it swings out gradually until it is in contact with the ring die. Another distinction between this mill and the Huntington is that in the former the roll is "underhung" instead of being "overhung," as in the latter.

The Griffin mill, as originally made, was equipped with a heavy iron frame, and many engineers still prefer this type of construction. It is now also made with what is known as a wooden or composite frame, equipped with wooden standards which rest on rubber blocks, thus increasing the elasticity of the framework, and cushioning the severe vibratory strains which are necessarily set up in machines performing this class of work. The mechanism of the universal joint has also been improved, so that larger bearing surfaces for the working parts are provided, aiding in the better distribution of the strains set up.

This mill runs at a pulley speed of 200 r.p.m., when the crushing effect of the roll against the die is about 6000 lb., consuming from 20 to 28 h.p. The internal diameter of the die is 30 in and the roll is 18 in. in diameter and 6 in. deep, the depth of the ring die being the same. The roller weighs about 600 lb. and the die about 300 lb.

Of recent years an improved mill has been evolved, known as the Giant Griffin, which is the machine illustrated. The design of this machine is substantially the same as that of the mill just described, with one or two alterations. For instance, the pulley body is now constructed so that all the wearing parts run in a bath of oil; the pulley rim is on the lower half of the pulley body, with the object of eliminating shearing stress in the bolts; the lower journal bearing is separate from the pulley body so as to decrease the cost of the wearing parts; and an increased screening area allows greater freedom of discharge. In this machine the diameter of the ring die is 40 in. and the roll is increased to 24 in. in diameter. The speed of the pulley is slightly lower than in the original Griffin mill, being 170 r.p.m. The crushing effect of the roll against the die is more than doubled, *i.e.*, 15,000 lb.

A similar machine is the Bradley mill, which is equipped with three rolls so arranged that they have a continuous tendency to rise when running, thus largely relieving the step bearing of the weight of the driving mechanism. In this mill the material to be dealt with is fed continuously on to the grinding ring immediately in front of the three advancing rolls. The diameter of the ring die is 42 in. and that of the rolls 16 in. The pulley revolves at 150 r.p.m., requiring from 35 to 40 h.p.

These three mills crush dry and the moisture in the feed should in no circumstances exceed 2 per cent. Owing to this fact other means than water have to be employed for discharging the crushed material. Scrapers are attached to the underside of the roll which serve to maintain the pan clear and to carry the material up into the crushing area. Above the roll are fixed to the shaft a pair of blades which create a current of air to blow the material against the screen surrounding the mill body. The material passing the screen falls into a boot underneath the pan, from whence it is removed usually by a screw worm conveyor.

The ordinary Griffin mill is suitable for crushing all classes of hard and refractory materials, provided they are not of a sticky or fibrous nature, to almost any fineness within the range of all passing a 6 or 8 mesh down to a small quantity on a 240 mesh.

The Giant Griffin mill performs the same class of work, but with slightly better finenesses, and produces from two-and-a-quarter to two-and-three-quarters the output, with a proportionate increase in power consumption. The wear and tear is slightly less than that of the Griffin mill.

The feed for the Giant Griffin should all pass a 1 in. ring. When grinding limestone, coal, cement, clinker and other refractory materials this mill will reduce from 1 in. to the necessary fineness in a single operation, the fineness being, of course, regulated by the screen used. It finds its field in dealing with such materials as coal, limestone, felspar, chrome, ore, slate, foundry facings and coke.

The Bradley three-roll mill will deal with similar substances provided that they are not too hard or of a cutting nature. This mill will give a finished product of anything between the ranges of all passing a 6 mesh down to 95 per cent. passing a 100 mesh sieve. The output is about one-and-three-quarters that of the 30-in. Griffin mill, with a proportionately increased power consumption. The Bradley mill is adapted for grinding such materials as limestone, coal and phosphate rock.

On these three mills the cost of wear and tear runs from 1*d.* to 9*d.* per ton of material ground. No closer figure than this can be given, since the cost must naturally vary with the class of substance dealt with and the degree of fineness of the finished product, which may be adjusted by changing the mesh of the screen surrounding the pen of the mills. It is not easy to make comparisons between the three mills unless operating conditions are identical, but the figures shown in Table I are instructive and show results from each of the three mills when dealing with agricultural limestone.

TABLE I.

	Improved 40 in. Giant Griffin Mill.	Bradley 3-Roll Mill.	30 in. Griffin Mill.
HARD CRYSTALLINE LIMESTONE:			
(1) *Fineness:*			
Passing 100 mesh per linear inch sieve.	80–85%	80–85%	80–85%
Output per hour.	5¾–6¾ tons	3¾–5 tons	2–2¾ tons
(2) *Fineness:*			
All passing 10 mesh per linear inch sieve.			
& % passing 100 mesh per linear inch sieve.	55%	55%	55%
Output per hour:	6¾–8 tons	4½–5½ tons	2½–3½ tons
Horse-power applied to Mill Pulley.	65–75 b.h.p.	45–50 b.h.p.	25–28 b.h.p.
Size of feed should not exceed all passing.	1″ ring	¾″ ring	¾″ ring

The 30-in. Griffin mill and Bradley 3-roll mill are in favour for the reduction of phosphate rock. For dealing with basic slag, the 30-in. and 40-in. Griffin mills just about share the honours, though it must be remembered that the 40-in. mill is a later introduction and was probably made available when installations of the smaller unit had already been carried out, and the change was not worth while. On agricultural limestone plants

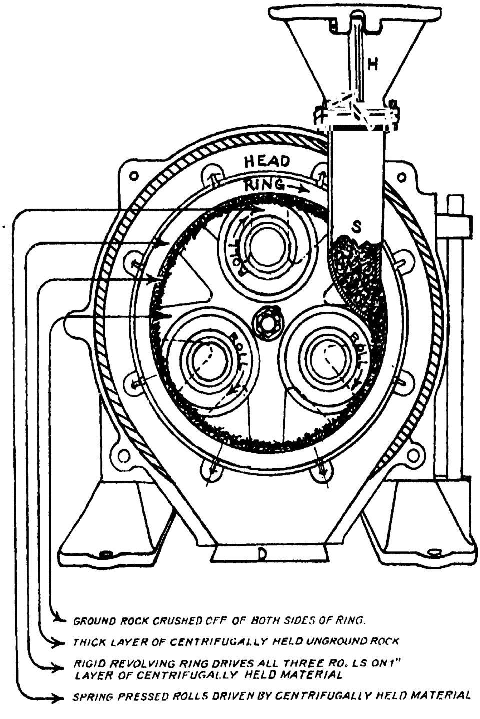
H
HEAD
RING
S
ROLL
ROLL
ROLL
D
GROUND ROCK CRUSHED OFF OF BOTH SIDES OF RING.
THICK LAYER OF CENTRIFUGALLY HELD UNGROUND ROCK
RIGID REVOLVING RING DRIVES ALL THREE ROLLS ON 1" LAYER OF CENTRIFUGALLY HELD MATERIAL
SPRING PRESSED ROLLS DRIVEN BY CENTRIFUGALLY HELD MATERIAL

Fig. 17.—Sturtevant Ring-roll Mill.

the Bradley and the 30-in. mills are used about equally.

A useful machine for reducing the hardest materials down to 8 mesh and finer is shown in Fig. 17. This is the Sturtevant ring-roll mill, and is employed for dealing with such materials as cement clinker, phosphate rock, granite, quartz, trap, ores of various kinds, slag, lime, limestone and cast iron chips. The principle of this machine is simple—a heavy steel anvil ring is secured in a head supported and revolved by the horizontal shaft, while against the inner face of this ring hammer rolls are elastically pressed and are revolved automatically with the ring. The material to be ground, usually about 1¼ in. size, is fed to the inner face of the rotating ring and held there by centrifugal force, being crushed as it is drawn between the convex roll faces and the concave ring surface. The roll force is adjusted by a screw on the outside of the door, whereby the pressure can be varied between 20,000 and 40,000 lb.

In operation the concave surface of the ring is always covered with a layer of the material being dealt with so that an uncovered track is not exposed to the roll faces. The material is fed constantly and as it is reduced falls away on both sides of the ring, escaping from the bottom of the casing. The mill is usually operated in a closed circuit so that the oversize material after screening is returned to the mill with the fresh feed.

None of the crushing stresses are taken by the head shaft, which merely serves to support and revolve the head. The rolls are elastic and balanced and will run over tramp iron or other uncrushable material without shaft breakage. The wear on the ring and the rolls is very small, and a ring will usually last more than two years even on the hardest materials, such as cement clinker.

A feature of this crushing mill is its accessibility. By removing four bolts the whole front of the casing opens like a door, carrying the rolls and their parts outside the mill and exposing the interior. When the door is closed the rolls are swung back into their place inside the ring and pressed back into position against the ring by operating a screw. When the mill is empty the rolls may be held away from the ring so that no wear takes place.

These mills are made in three sizes, the smallest having an output of ½ to 4 tons per hour with 8 to 12 h.p., and the largest an output of from 2 to 15 tons consuming 25 to 45 h.p.

A similar machine is the Maxecon mill in which the operating principle is a free vertical concave ring, yieldingly supported on three rolls pressing against its inner face and having a free movement relative to each other. The object of the lateral freedom of the ring is to allow it to adapt its position relatively to the material being ground, with the view of attaining the line of least resistance to crushing of the material.

In this mill the ring revolves and the three rolls press against its inner face, the four wearing parts being the three convex rolls and the concave ring. The rolls are supported yieldingly by springs and the ring is supported by the rolls, so that the four crushing parts are free to move to pass iron or other uncrushable material.

For this machine no special foundation is required; two 12 in. by 12 in. timbers placed on any suitable floor are sufficient, with the mill fastened down by four ¾ in. by 6 in. lag screws. Practically the whole of the vibration is absorbed in the mill and is not transmitted to the foundation. The speed is 200 r.p.m. and the feed should not exceed 2 in.; 1 in. is better.

Though it cannot actually be classified as a centrifugal roll mill, the Chilian mill is similar in operation, in that the material is crushed between a cylindrical roller and an annular die. The raw material is fed, together with water, at the periphery of the mill and is not only crushed by the weight of the rollers, but is also subjected to a shearing action due to the fact that the rollers are forced out of the normal straight line of travel and made to move in a circular path.

The general appearance of the Evans-Waddell mill is not greatly different from that of others of the same type. The machine operates on the well-known plan of the old-time Chilian mill, one of the earliest devices known for the grinding of ore.

The chief distinguishing feature of this machine is the method of mounting and driving the crushing rollers. These rollers, three in number, are made with a long hub and are mounted on the arms of a central spider made of a steel casting, the centre of which is shaped to receive a cast-iron ball, on which ball the spider is a working fit. The ball itself, being a sliding fit on the vertical shaft, allows the rollers to rise and fall as the thickness of the bed of ore on the die, or the wear of the die and rings, may require. The axes of the rollers are thus kept in the same plane and approximately horizontal, and by this means keep the wearing faces of the rings and dies in proper condition. The rollers have large bronze-lined bearings on the centre spider, the arms of which extend through and support the rollers out beyond the point where the work is being done. These bearings in the case of a 6-ft mill are 7 in. in diameter and 28 in. in length.

The spider carrying the grinding rollers is rotated by means of a driver mounted on feather keys on the vertical shaft above the spider and connected to it by means of three heavy flat connecting links arranged 120° apart. These links

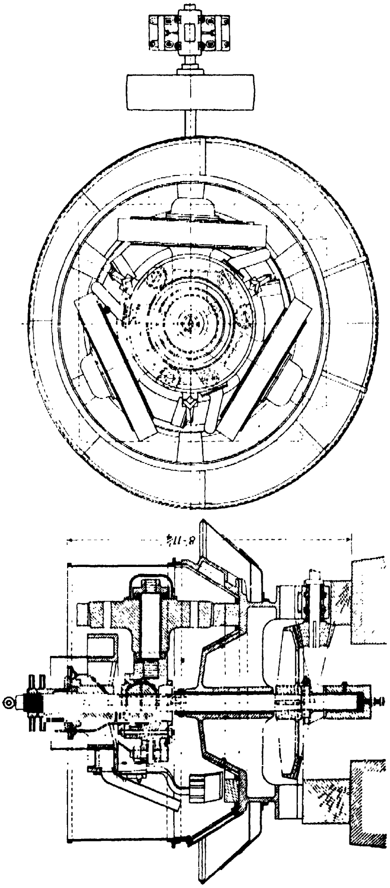

FIG. 18.—EVANS-WADDELL CHILIAN MILL.

are a loose fit on the pins to which they connect, so as to admit of the rollers running freely over any unevenness in the bed of material being ground, and at the same time allowing considerable latitude in the vertical adjustment of the driver upon its shaft.

The driver, which also forms an annular pan for receiving and distributing the feed, is adjusted downwards upon the shaft as the dies wear out. No fine adjustment, however, is required, as all that is necessary is to have the connecting links drawn somewhere near in a horizontal line. The mortar, or pan, of the machine is heavy and is lined throughout its inside surfaces with hard iron wearing plates. The seat on which the die ring rests is also very heavy. The upper bearing for the centre shaft which is carried by the mortar is of ample proportions and is fitted with a removable bronze bushing. This bearing in the case of a 6-ft. mill is 7 in. in diameter and 3 ft. long.

The screen openings, of which there are six, of large proportions, are so arranged as to admit of a free discharge of the material being ground. The screens are held in cast-iron frames arranged to bring the inside surfaces even with the inside surface of the mortar liners. The bottom edge of the screen surface is placed low enough with relation to the face of the die ring to ensure free screening during the full life of the die ring.

Above the screen and carried by the mortar is a sheet steel housing extending upward sufficiently high to retain the splash of the material being ground.

The outside of the mortar is shaped to form a circular spout or launder. Attached to this launder is a sheet of steel guard to retain the splash of the screen discharge. This guard is so placed as to admit of ready inspection or removal of the screens. The bridgetree is readily removable, as is also the bronze bushing with which the step bearing is fitted. The driving pinion is of steel, mounted on a shaft fitted with tight and loose pulleys or with friction clutch, as desired. The driving shaft is mounted in boxes fitted with removable babbitted wearing sleeves.

The oiling of the upper bearing of the vertical shaft and the three crushing roller bearings is by means of hose and pipe connections leading from a central oil cup on the top of the vertical shaft. The driving shaft boxes and the step bearings are oiled by separate oil cups. The crushing rollers are provided with oil-tight caps on their outer hubs which retain the oil and make their bearings practically self-oiling. The die ring and roller shells or tyres are of forged steel. In addition to being able to run for long periods continuously except for interruptions made necessary by the renewal of roller rings and dies, the machine is so constructed that when the repairs do become necessary they can be accomplished with the minimum loss of time. In this machine the rollers are held in the position most favourable for doing efficient work and for keeping the rollers and die faces in perfect condition.

The machine is made in two sizes, 6 ft. and 5 ft. The capacity depends upon the character and size of the ore and upon the size of openings in the screen. In the case of a 6-ft. mill working on Butte, Montana, copper ore, the machine is fitted with 12 mm. × 1¼ mm. screens, and handles 160 tons per 24 hours of material previously crushed to pass a ¼-in. screen. In another case the mill is fitted with 12 mm. × ¾ mm. screens, and on a feed, the coarsest of which has passed a ¼-in. screen, supplies all that can be taken care of by seven concentration tables, equal to 100 tons or over in 24 hours.

Under similar conditions the 5-ft. mill would be capable of about 100 tons and 60 tons respectively. Working on the product of an ordinary breaker at the Utah Copper Co.'s Bingham plant, the ore being fed at about ¾ in. cube to a 6-ft. mill fitted with wire screens with holes ·0156 in. the output was 96 tons in 24 hours using 2 tons of water per ton of ore. Under similar conditions the 5-ft. machine would be capable of about 50 tons per 24 hours.

The weight of the 6-ft. machine is 60,000 lb. and of the 5-ft. 35,000 lb. The weight of the mortar of the 6-ft mill, which is the heaviest piece, is 12,000 lb. In the 5-ft. machine the mortar is made in sections, and the mill can be taken apart so that no piece exceeds 1 ton in weight. The total crushing weight of the rollers and their carrying spider in the 6-ft. mill is 23,000 lb., and in the 5-ft. mill 13,500 lb. The 6-ft. mill has driving pulley (tight and loose) 48 in. diameter × 12 in. face; speed 140 r.p.m., speed of vertical shaft 37 r.p.m. The 5-ft. mill has driving pulley (tight and loose) 42 in. diameter × 12 in. face; speed 140 r.p.m., speed of vertical shaft 43 r.p.m.

DIRECTOR ... BENGAL.
-12 OCT 1925

CHAPTER VII

BALL AND ROD MILLS

Ball and rod wet grinding mills are similar in construction and may therefore be considered together. This is not to say that their applications always coincide, in fact, their uses are more or less distinct; but it is not easy to say just where a ball mill is more suitable than a rod mill, or *vice versa*; each case must be judged on its merits.

In construction, each machine consists of a shell of cylindrical shape rotating about an axis parallel to its length, the raw material entering at one end and the ground product leaving at the other. The feeding device varies, but as a rule it is a spiral scoop of large or small diameter, depending upon the amount of feed and the height it requires to be elevated from the actual point of delivery into the mill. The mill shells are equipped with a renewable lining, which is of different designs with the object of providing the desired action within the grinding space. Reduction is effected by steel balls or pebbles in the ball mill and rods in the rod mill.

The object of the ball mill in general is to turn out a granular product, so that it is relatively short with the view of not carrying reduction beyond a certain point. As a general rule rod mills produce less fines than the ball mill, consequently they can be constructed sufficiently long to retain the rods in their axial line without detriment to the nature of the product. In practice, rod mills are intermediate in length between ball and tube mills.

The rate of feed in both ball and rod mills has a great determining influence on the character of the product. The tube mill discharges at the same rate at which it is fed, and the fineness of its product can be regulated only by the charge of grinding media, in this case pebbles, and the amount of water in the feed. The other central discharge mills are correspondingly influenced by the ball or rod charge and the ratio of water to solids in the feed, but some mills are constructed with an annular discharge which permits the free egress of the product, resulting in a greater capacity and comparative freedom from fines.

The speed of rotation of ball and rod mills depends upon the diameter of the mill and cannot be varied without some loss of efficiency.

A typical modern ball mill is illustrated in Fig. 19 (Colorado). Used upon work to which it is suited the ball mill forms a very satisfactory and economical machine, though it cannot be said to be more suitable for any and every class of work than all other types of grinding machinery, as has been claimed by some enthusiasts. The fact is that we have in the ball mill a highly efficient grinder for quite a wide range of work, but it was never intended to supplant all other grinding machinery;

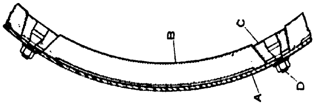

Fig. 19*a*.

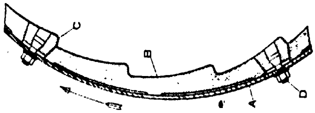

Fig. 19*b*.

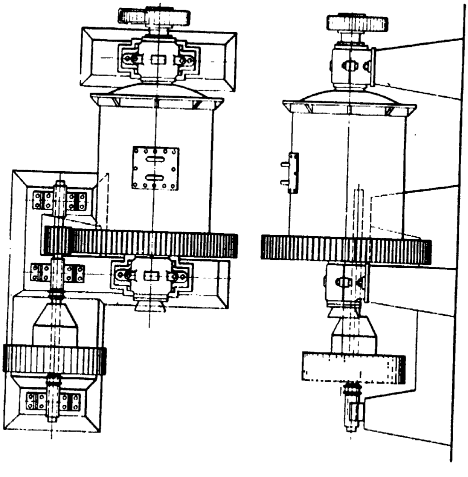

Fig. 19.—Colorado Ball Mill.

it has its own particular field in reduction operations, and in this field it is very hard to beat.

It is certainly true that the feed to ball mills may be as coarse as 2 in. or 3 in. and that such feed can be reduced to high degrees of fineness, but in taking a very coarse feed it will not compare in efficiency with rolls, while for producing a very fine product it is not as suitable as the tube mill.

The disadvantage of the coarse feed disappears in a small installation because crushing rolls show their chief economy in operating cost per ton crushed, and in small plants low first cost and simplicity of equipment cause the ball mill to be the most economical when the total cost of reduction as a whole is the dominating factor. There are many cases where the ball mill shows a very decided advantage over other grinders, but no hard and fast rule as to its scope can be laid down. All the conditions must be taken into consideration.

There are conditions under which ball mills form most suitable units for secondary reduction, taking the product from a jaw or gyratory crusher and reducing it to a granular product. Such conditions are found mostly in small plants where first cost of equipment and installation enters very largely into the total cost. On the other hand, in large plants, the most economical system is to reduce the primary crusher product to about

¾ in. in heavy rolls, and then to finish it off in ball mills.

Ball mills with a central discharge perform the maximum amount of work on the raw material sent into them, and if a granular product is required the tonnage feed should be as great as the mill will satisfactorily deal with and still be reduced to the desired fineness. Too heavy a feed will mean that the material will not be sufficiently treated and the resulting product will be too coarse; if the feed is too light the product ground will be beyond the fineness required.

As a general rule some means of outside classification operating in closed circuit with the mill will give the best results, the function of such a classifier being to do outside what cannot advantageously be carried out inside the mill. The classifier is adjusted to overflow a product of the desired fineness, while the coarse material is returned for regrinding through the feed inlet. Such a continual return of insufficiently ground material, in addition to the raw feed to the mill, gives the latter a circulating feed in excess of the initial feed, and greatly increases its efficiency by enabling it to produce a large amount of pulp of the desired fineness instead of a smaller amount containing a large amount of dust when grinding dry, or slime when grinding wet. The charge of balls in the mill and the amount of water in the feed when grinding are naturally adjusted to favour the greatest output with the minimum wear and tear.

When crushing ores for table concentration, where a relatively coarse, granular product as free from slime as possible is desired, the ball mill with annular discharge through a grating offers advantages over the central discharge mill. The grating is not intended actually to size the product, but to pass freely all pulp which is sufficiently fine, while retaining the balls and the coarse ore. The outside classification of the product is not dispensed with, but the reduction of slime is decreased, and as the energy otherwise consumed in sliming is employed in grinding coarser ore, the capacity is increased.

Ball mills, such as the type illustrated in Fig. 19, are constructed in a variety of sizes and driven in various ways to suit best the particular conditions obtaining.

The feed is through a spiral scoop of varying pattern to suit the work. The discharge trunnion is equipped with a flared lip and, where it is of benefit, a renewable reverse spiral to prevent the egress of balls and coarse ore.

In place of the usual blank head liner another is used in the discharge end of these mills, comprising an outer ring of blank liners, an annular grating, and a blank central liner. The head liners rest upon the ribs of the head, these ribs serving to lift the pulp which passes through the grating and discharge it into the trunnion. This grating is held simply and is easily renewable. There is no difference in outward appearances between the annular discharge and the central discharge mills, and they are readily convertible one into another.

The shell linings of ball mills are of different types, and a certain form of lining will finally be settled on in each case after the mill has been operating long enough for a careful judgment to be formed. The best type of lining cannot be foretold with certainty, and in some cases the advantage of the more expensive linings will be found to consist in increasing the intervals between replacements rather than in any decided reduction in the cost per ton of material treated.

In general, hard iron liners may prove entirely satisfactory for use with small and medium size balls, but for use with large steel balls steel liner plates are usually essential. The simplest liner is the plain type shown in Fig. 19*a*. This consists of plain plates, B, of any specified thickness, with two of their edges bevelled to match the key liners, C, which fasten the whole to the shell, A, by means of the bolts, D.

The wave liner is usually made 2 in. thick at the thinnest part, increasing to 3 in. at the crest of the wave. This has proved a satisfactory liner for initial installations where experience has not yet been acquired, and although the life of such a liner is not so great as one of alloy steel, the cost is less and the cost per ton ground may compare very favourably with the more resistant but more costly material. This form of liner is indicated in Fig. 19*b*.

The shell of the mill is shown at A and the liner at B. The liner plates are made in sections extending circumferentially, and the sections have their keys bevelled to match the key liners, C, these key liners alone being bolted through the shell by the countersunk head bolts, D. The arrow indicates the direction of rotation of the mill.

The balls are used of various kinds of material, both cast and forged, and, as in the case of the lining, a longer life involves a higher cost. The balls in this mill are fed daily to compensate for wear. Balls of 5-in. down to ¾-in. diameter are used, the largest being advisable only in ball mills taking a crusher product, 2½ in. being the most efficient maximum size for such work as regrinding.

The initial charge should contain balls of all sizes from the chosen maximum down to the smallest, and it is usually necessary to feed a certain proportion of small balls to maintain a proper assortment within the mill, although in some plants it is the practice to feed only the largest size after the mill has been once charged with a proper assortment of the different sizes, and to depend upon the wear of the balls for the supply of the smaller sizes.

These mills are made in sizes ranging from 3 ft. × 3 ft. to 7 ft. × 10 ft. The smallest mill turns at 30 r.p.m. with 6 h.p., the ball charge weighing 18 cwt. The largest mill turns at 19 r.p.m. with 222 h.p., the ball charge weighing 17½ tons.

The Marcy ball mill, designed specifically for wet grinding, has almost the entire discharge end fitted with grates. Between the grate and the end of the mill there are arranged lifters which act as a pump to lift the product so that it will be discharged through the discharge trunnion of the mill. Water and feed enter the mill through the feed trunnion, consequently there is a difference in elevation between the feed as it enters the mill and the point of discharge through the grate.

This mill has found its greatest application in the crushing of coarse materials, from 3 in. to ½ in. in size, to 10 mesh in one pass of the mill, in which the capacity ranges from 25 to 1000 tons per day.

To get the best from this machine it should be operated so that the pulp is low in the mill. With the proper proportion of ball charge and feed the mill should be noisy, and to maintain this condition a constant rate of feed of water and raw material should be provided. If motor drives are used the motor should be connected with an ammeter in full view of the mill operator. The feed should then be adjusted to maintain a constant amperage, which, if it drops, indicates that the mill is overloaded.

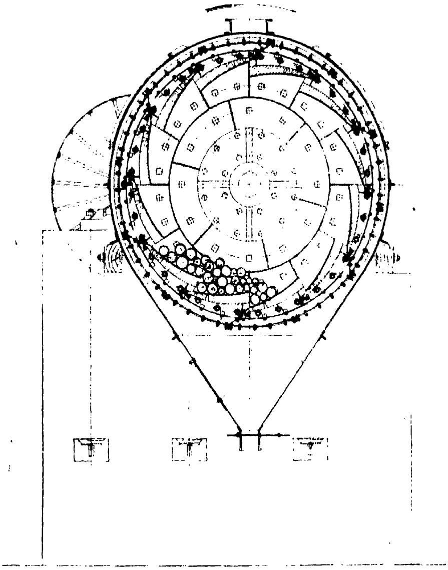

FIG. 20.—STAG BALL MILL.

A simply constructed ball mill of the perforated screen type is shown in Fig. 20 (Allen's Stag Mill). This type is applicable to the reduction of mineral ores, cement clinker, slag, quartz, coal and other refractory materials. It can also be used as a preliminary grinder for treatment in a tube mill; when so used no dressing machines are required, practically any degree of fineness can be obtained and supervision is minimised.

This mill is employed both for wet and dry grinding, with or without sieves. The periphery is formed of hard steel grinding plates which, being perforated, allow the material when ground fine enough to leave the mill inner chamber. Four perforations may be seen in the drawing near the thin end of each plate. That portion of the material passing from the inner chamber falls on to a second perforated plate or check sieve which allows only the finer material to enter the outer chamber, on which is fixed a final series of sieves so arranged as to pass only the necessary fineness.

In each stage the rejected material, *i.e.*, that too coarse to pass the respective screens, is returned automatically to the inner chamber for further reduction, so that the process of grinding is continuous and automatic. The ground material is delivered from the bottom or hopper section of the chamber into bags by operating a slide, or the bottom may be left open for the finished material to be carried away by a conveyor or in tubs.

The following parts are subject to wear and are renewable: the grinding plates and forged steel balls, punched steel check sieves and perforated plates, the woven steel wire gauze and the small grit sieve.

The side plates, which are of rolled steel in the larger sizes and of cast iron in the small sizes, are mounted on cast-iron centres keyed to the main shaft. The feed hopper is bolted to the inner edge of the main sole plate.

Material up to 7 in. cube can be fed to the largest mill, but the usual size of feed is 2 in. cube. When operating on shale for producing stone dust, a special grit sieve allows from 5 to 10 per cent. of the shale to leave the mill as a fairly coarse grit by reducing the percentage passing the 30, 35 or 40 mesh screen, without materially reducing the finest product.

In the Hardinge conical mill the principle of operation is the rotation of a number of grinding bodies inside a drum which consists of a flat cone and a steep cone riveted to a cylinder. The grinding bodies, in dropping, reduce the material which is passed to and from the grinding zone through hollow trunnions supporting the drum.

The object of the conical shape is to secure a natural segregation of both the grinding balls and the material under treatment. The coarse material on entering the mill through the hollow feed trunnion is reduced by the largest balls or pebbles which are kept near the feed end by the classifying action of the cone. This principle will be understood on reference to the drawing, where it will be seen that the peripheral speed of the mill at its largest circumference, *i.e.*, the cylinder, is 650 ft. per minute, at the middle of the steep cone it is 400 ft. per minute, and near the outlet it is only 250 ft. per minute.

As the lumps of raw material are broken by the largest balls the particles work their way forward, thus being subjected to a grinding action gradually diminishing in intensity, so that the material acquires the required degree of fineness simultaneously with its arrival at the discharge.

This automatic segregation means that the largest lumps are left to be dealt with by the biggest and heaviest bodies, without being clogged up with finer material. Thus each particle is automatically classified with a simultaneous segregation of the balls, so that each different size particle is dealt with by the appropriate grinding agent.

The Hardinge mill is constructed in both ball and pebble types; both operate in a very similar manner, and, though they overlap to a certain extent, the pebble mill has applications where the ball mill has not. Generally speaking, the ball mill is used for grinding ores and similar materials either wet or dry from sizes up to 3 in., reducing the material to any degree of fineness.

The pebble mill using flint pebbles as a grinding medium can take as a maximum a $\frac{3}{4}$-in. feed, though the best results are obtained when the feed is reduced below ¼ in. Such a mill is able to deliver either a very granular or a very fine product by changing the speed, the pebble load, and by effecting one or two other minor alterations.

The pebble mill, for the space occupied, has less capacity than the ball mill, though operating costs for the pebble mill are usually lower on account of the expense of the cast-iron or forged steel balls in the ball mill.

The chief functions of the pebble mill are in the grinding of felspar and silica, and where materials are ground in certain acids which would eat the metallic lining of the ball mill.

The conical mill finds its chief application in the metallurgical field where it was first introduced as a granulator to grind for table concentration. Another typical application is in the recovery of minerals by flotation. The object here is to grind the gangue fine enough to release the mineral without sliming; in the conical mill overgrinding is avoided by the selective action of the body. For instance, a conical mill, using 5-in. or 6-in. balls, is employed as a primary unit to take a feed of 2 in. and reduce it to either 10 or 20 mesh, the re-grinding mill taking the product of the primary mill and reducing it to 80 mesh or finer. In some cases the mill performs both the primary and secondary grinding.

Other general uses of the conical mill are for grinding cement, for pulverizing fuel, and for crushing phosphate rock, silica, enamel frit, grog, ink, barytes both wet and dry, sulphur, asbestos, cast-iron borings, and such abrasives as garnets, emery and carborundum.

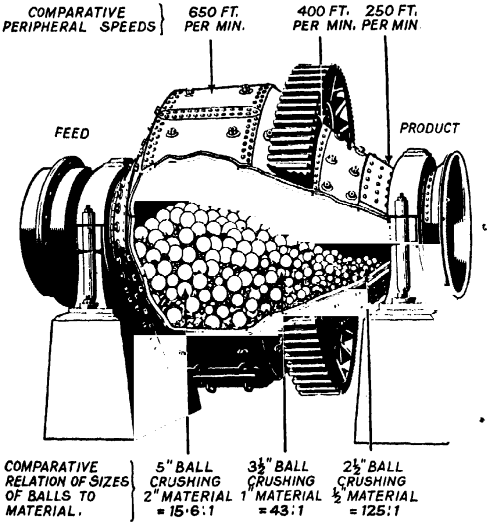
COMPARATIVE PERIPHERAL SPEEDS
650 FT. PER MIN.
400 FT. PER MIN.
250 FT. PER MIN
FEED
PRODUCT
COMPARATIVE RELATION OF SIZES OF BALLS TO MATERIAL.
5" BALL CRUSHING 2" MATERIAL = 15·6:1
3½" BALL CRUSHING 1" MATERIAL = 43:1
2½" BALL CRUSHING ½" MATERIAL = 125:1

Fig. 21.—Hardinge Conical Mill.

Both the ball and the pebble mills are of similar construction, the only difference being that the ball mill in the larger sizes is designed to withstand much heavier loads and is equipped with a different lining.

The drums of the smaller mills, namely, the 2-ft., 3-ft., 4-ft., and 5-ft. mills, are of cast iron, in both the ball and the pebble mills. The larger mills, 6 ft., 7 ft., and 10 ft. in diameter, are constructed of two plate steel cones jointed to base with a short cylindrical wrapper piece.

The ball or pebble mills may be driven in any one of the following three ways :

(*a*) Spur gear and pinion, using a countershaft and pulley drive for belting from either line shaft or motor.

(*b*) Spur gear and pinion, using countershaft and chain drive direct to motor or line shaft.

(*c*) Herringbone gear and pinion for direct connection through a flexible coupling to a motor shaft.

The method of feeding these mills varies according to the material under treatment.

The reversible scoop feeder is usually employed for feeding wet materials, and is attached to the mill trunnion by a cast iron extension piece, taking up its charge by scooping material from a receptacle with each revolution of the mill.

For the smaller mills grinding both wet and dry the conical feeder is best. In this case the feed is passed direct into an opening from which the scoop picks it up and discharges it into the trunnion.

The drum feeder is used for wet grinding on the larger ball and pebble mills where it is desired to feed material directly into the mill, and where any returned oversize need not be picked up from a lower level than the central axis of the machine.

When coarse material has to be fed and oversize from the classifier has to be returned, a combination of the drum and scoop feeders answers the purpose.

For dry grinding a screw feeder is necessary to force the material into the mill. In this type the material is discharged on to a table through a spout just above it and centred. A large adjustable knife cuts the cone of feed so formed and sends a continual stream into the hopper of the screw feeder.

In other cases a table and chute feeder is used, for instance, where the capacity is not too heavy. For fine feeds an undershot rotary feeder is general.

All the conical mills are lined with either metal or flint blocks, depending upon the type and work required. These linings are replaceable in sections.

The standard lining for the ball mill is a combination of chrome steel and charcoal chilled iron. The wearing bar, which projects a little above the plate and is held in place by taper bolts, is made of chrome steel and serves the three-fold purpose of meeting the major impact of the balls, lifting the mass of material, and holding the plates in place.

The pebble mill is usually equipped with a flint lining, though in some cases metal linings are installed. The flint lining is either a hard Belgian Silex block or a flint block. The blocks are held in place by cement or special compositions where the use of cement is open to objection, *e. g.*, grinding in acid.

The size and character of the balls used depend to a large extent upon the nature of the grinding and the amount of work to be undertaken. Generally speaking, for a feed of fairly hard material larger than ½ in., all-steel balls are used, usually a combination of 5-in., 4-in., 3-in., and 2-in. balls. For feeds below ½ in. cast-iron balls are usual, ranging in size from ⅞ in. to 2½ in.

In the pebble mills flint pebbles, usually from France or Denmark, are employed, varying in size from 1 in. to 8 in. according to the size of the mill and the work to be carried out.

Most of what has been said about the ball mills applies to rod mills, and it is therefore not necessary to repeat it. It will readily be understood that rods give a line instead of a point contact, as is the case where balls are used, and the large particles of material serve to protect the small particles, so that a tendency to reduce the amount of slime is produced. Rods also exert the maximum crushing effect as the entire weight of each rod is transmitted to the material being ground. The early attempts to employ rods were not very successful, owing to faulty mechanical construction of the mills, but heavy, well-designed modern rod mills have demonstrated their efficiency, and this type is gaining favour among even the most exacting operators.

Rod mills of the Colorado design, typical of modern construction, are made in sizes from 4 ft. × 8 ft. to 6 ft. × 14 ft. The smallest rod mill turns at 27 r.p.m. with 35 h.p., the charge of rods weighing 4 tons 16 cwt.; the largest mill turns at 21 r.p.m. with 222 h.p., the rod charge weighing 19 tons 6 cwt. These rod charges are approximate only as they vary with the thickness of the lining and the height in the mill to which it is found best to carry the rods in the particular conditions obtaining in each case.

The Marcy rod mill takes a 1-in. crusher feed and reduces it to 8–20 mesh in one pass. In grinding for flotation, amalgamation or cyanidation or other fine grinding, the mill is operated in closed circuit. It may be used either for dry or wet grinding.

A feature of this mill is the open-end construction with the view of maintaining a low pulp line. This door provides access for inspection and repairs, though it may be opened while the mill is operating. It has been used successfully in dealing with dry materials such as limestone, phosphate rock, gypsum, crushed stone, glass, sand, shale, clay, talc and for pulverizing coal. The capacity ranges from 5 to 1500 tons per day of 24 hours.

During the last year (1923–1924) a great deal of experimental work has been done in connection with the dry grinding of various materials in the rod mill, and these tests indicate that as a dry grinding machine the rod mill is most efficient, and it is now being recommended for dry grinding problems. The rod mill has several points in its favour. In the ball mill little can be used but manganese steel, as it is the only material that will stand up. The rod mill can be lined with a hard car wheel iron liner which will give very satisfactory wear. This is probably due to the fact that in a ball mill we have a point contact, whereas in a rod mill we have a line contact. Car wheel liners will vary from one-third to one-half the cost of manganese steel, depending upon the size of the mill. Special high carbon steel grinding rods containing about 1 per cent. carbon are used in Marcy rod mills, costing about one-half the figure for steel forged balls, so that the wearing parts and the grinding medium in the rod mill are less expensive than in the ball mill.

There is more weight per unit volume in the rod load than in a ball load by about 26 per cent. There are not so many voids in a rod load as in a ball load, with the result that there is not the tendency for the material to sift through the rod load that there is for it to sift through the ball load. Rods in the rod mill act very much like a multiple set of rolls, the grinding being done very largely by attrition between the rods. As the mill barrel revolves and the rods are carried up the side of the mill the rods act somewhat as an elevator, locking the feed in the rod load and carrying it along with them. The rod mill will produce a more evenly ground product than the ball mill, and contains less oversize and is ideal for table concentration or flotation. The rolling action of the rods has a tendency to cut down the horse-power necessary for the mill, and in general it will be found that, of a rod mill or ball mill having the same capacity, the rod mill will require less power.

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